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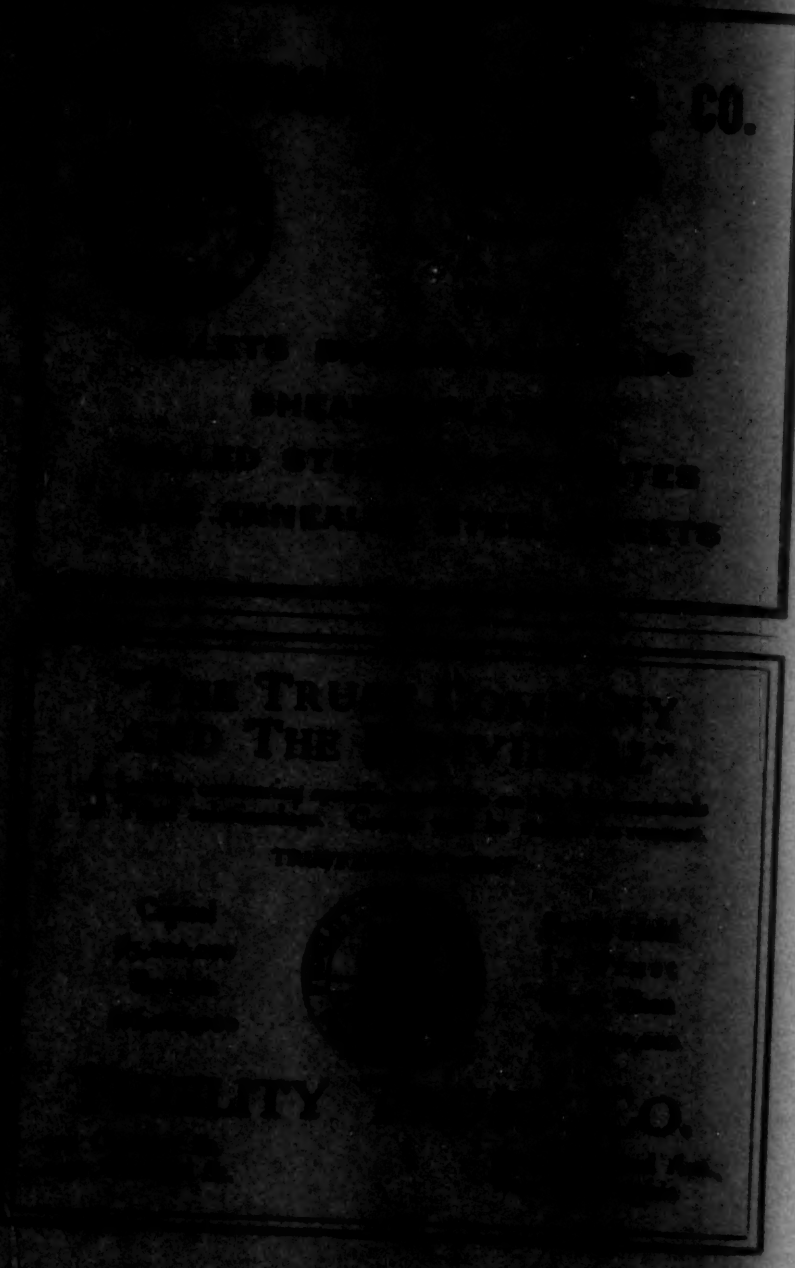

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THE NATURAL AND ARTIFICIAL DISINTEGRATION OF THE ELEMENTS.*

BY

PROFESSOR SIR ERNEST RUTHERFORD, Kt., D.Sc., LL.D., Ph.D., D.Phys., F.R.S.

Franklin Medalist, Member of the Institute.

It is not my intention in this paper to give a detailed account of the natural disintegration of the radio elements or of the methods employed to effect the artificial disintegration of certain light elements. I shall assume that you all have a general knowledge of the results of these investigations, but I shall confine myself to a consideration of the bearing of these results on our knowledge of the structure of the nuclei of atoms.

There is now a general agreement that the atoms of all elements have a similar electrical structure consisting of a central positively charged nucleus surrounded at a distance by the appropriate number of electrons. From a study of the scattering of α-particles by the atoms of matter and from the classical researches of Moseley on X-ray spectra, we know that the resultant positive charge on the nucleus of any atom, in terms of the fundamental unit of electronic charge, is given numerically by the atomic or ordinal number of the element, due allowance being made for missing elements. We know that with few exceptions

* Address delivered Thursday, September 18, 1924, on the occasion of the observance of the centenary of the founding of The Franklin Institute.

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all nuclear charges from 1 for the lightest atom, hydrogen, to 92 for the heaviest element, uranium, are represented by elements found in the earth. The nuclear charge of an element controls the number and distribution of the external electrons, so that the properties of an atom are defined by a whole number, representing its nuclear charge, and are only to a minor degree influenced by the mass or atomic weight of the atom.

This minute but massive nucleus is, in a sense, a world of its own which is little, if at all, influenced by the ordinary physical and chemical forces at our command. In many respects, the problem of nuclear structure is much more difficult than the corresponding problem of the arrangement and motions of the planetary electrons where we have a wealth of available information, both physical and chemical, to test the adequacy of our theories. The facts known about the nucleus are few in number, and the methods of attack to throw light on its structure are limited in scope.

It is convenient to distinguish between the properties assigned to the nucleus and the planetary electrons. The movements of the outer electrons are responsible for the X-ray and optical spectra of the elements and their configuration for the ordinary physical and chemical properties of the element. On the other hand, the phenomena of radio-activity and all properties that depend on the mass of the atom are to be definitely assigned to the nucleus. From a study of the radio-active transformations, we know that the nucleus of a heavy atom not only contains positively charged bodies, but also negative electrons, so that the nuclear charge is the excess of positive charge over negative. In recent years the general idea has arisen that there are two definite fundamental units that have to do with the building up of complex nuclei, *viz.*, the light negative electron and the relatively massive hydrogen nucleus which is believed to correspond to the positive electron.

This view has received very strong support from the experiments of Aston on isotopes, in which he has shown that the masses of the various species of atoms are represented nearly by whole numbers in terms of O = 16. From the general electric theory, it is to be anticipated that the mass of the hydrogen nucleus in the nucleus structure will be somewhat less than its value 1.0077 in the free state on account of the very close packing of the charged units in the concentrated nucleus. From Aston's experiments, it

appears that the average mass of the hydrogen nucleus, or proton as it is now generally called, is very nearly 1.000 under these conditions. We should anticipate that the whole number rule found by Aston would hold only to a first approximation, since the mass of the proton must be to some extent dependent on the detailed structure of the nucleus. In the case of tin and xenon, Aston has already signalized a definite departure from the whole number rule and no doubt a still more accurate determination of the masses of the atoms will disclose other differences of a similar kind.

While our present evidence indicates that the proton and electron are the fundamental constituents of the nucleus, it is very probable that secondary combining units play a prominent part in nuclear constitution. For example, the expulsion of helium nuclei from the radio-active bodies indicates that the helium nucleus of mass 4 is probably a secondary unit of great importance in atom building. On the views outlined, we should expect the helium nucleus of charge 2 to be built up of four protons and two electrons. The loss of mass in forming this nucleus indicates that a large amount of energy must be liberated during its formation. If this be the case, the helium nucleus must be such a stable structure that the combined energy of four or five of the swiftest α-particles would be necessary to effect its disruption. Such a deduction is supported by our failure to observe any evidence of disintegration of the swift particle itself, whether it is used to bombard matter or whether the α-particle is used to bombard other helium atoms.

On these views we should anticipate that the nucleus of radium of atomic number 88 and atomic weight 226 contains in all 226 protons of mass 1, and 138 electrons. While this gives us the numerical relation between the two fundamental units, we have, at present, no definite information of their arrangement in the minute nuclear volume nor of the nature and magnitude of the forces that hold them together. We should anticipate that many of the protons and electrons unite to form secondary units, *e.g.*, helium nuclei, and that the detailed structure of the nucleus may be very different from that to be expected if it consists of a conglomeration of free protons and electrons.

It is thus of great importance to obtain definite evidence of the nature and arrangement of the components of the nucleus and of

the forces that hold them in equilibrium. We shall now consider some of the lines of evidence which throw light on the actual dimensions of the nucleus and the law of force operative in its neighborhood; the structure and modes of vibration of the nucleus together with the effects observed when some light nuclei are disintegrated by bombardment with α-particles.

DIMENSIONS OF THE NUCLEI AND THE LAW OF FORCE.

The conception of the nucleus atom had its origin in 1911 in order to explain the scattering of an α-particle through a large angle as the result of a single collision. The observation that the α-particle is in some cases deflected through more than a right angle, as the result of an encounter with a single atom, first brought to light the intense forces that exist close to the nucleus. Geiger and Marsden showed that the number of particles scattered through different angles was in close accord with the simple theory which supposed that, for the distance involved, the α-particle and nucleus behaved like charged points repelling each other according to the law of the inverse square. The accuracy of this law has been independently verified by Chadwick, so that we are now certain that in a region close to the nucleus the ordinary laws of force are valid.

These scattering experiments also gave us the first idea as to the probable dimensions of the nuclei of heavy atoms, for it is to be anticipated that the law of the inverse square must break down if the α-particle approaches closely to, or actually enters, the nuclear structure. This variation in the law of force would show itself by a difference between the observed and calculated numbers of particles scattered through large angles. Geiger and Marsden, however, observed no certain variation even when the α-particles of range about 4 cm. were scattered through 100° by a gold nucleus. In such an encounter, the closest distance of approach of the α-particle to the centre of the nucleus is about 5×10^{-12} cm., so that it would appear that the radius of the gold nucleus, assumed spherical, could not be much greater than this value.

There is another argument, based on radio-active data, which gives a similar value for the dimensions of the radius of a heavy atom. The α-particle escaping from the nucleus increases in energy as it passes through the repulsive field of the nucleus. To fix a minimum limit, suppose the α-particle from uranium gains all its energy from the electrostatic field. It can be calculated

on these data that the radius of the uranium nucleus cannot be less than 6×10^{-12} cm. This is based on the assumption that the forces outside the nucleus are repulsive and purely electrostatic. If, as seems not unlikely, there also exists close to the nucleus strong attractive forces, varying more rapidly than an inverse square law, the actual dimensions may be less than the value calculated above.

At this stage of our knowledge, it is of great importance to test whether the law of force breaks down for the distance of closest approach of an α-particle to a nucleus. This can be done by comparing the observed with the calculated number of α-particles scattered through angles of nearly 180°. It seems almost certain that the inverse square law must break down when swift α-particles are used. This can be seen from the following simple argument. If an α-particle, of the same speed as that ejected during the transformation of uranium, is fired directly at the uranium nucleus, *it must penetrate into the nuclear structure.* If a still swifter α-particle is used, *e.g.*, that from radium C, which has about twice the energy of the uranium α-particle, it is clear that it must penetrate still more deeply into the nuclear structure. This is based on the assumption that the field due to a nucleus is approximately symmetrical in all directions. If this is not true, it may happen that only a fraction of the head-on collisions may be effective in penetrating the nucleus. It is hoped soon to attack this difficult problem experimentally.

We have so far dealt with collisions of an α-particle with a heavy atom. We know, however, from the results of Rutherford, Chadwick, and Bieler that in a collision of an α-particle with the lightest atom, hydrogen, the law of the inverse square breaks down entirely when swift particles are used. Not only are the numbers of H nuclei set in swift motion much greater than is to be expected in the simple-point nucleus theory, but the change of number with the velocity of the particle varies in the opposite way from the simple theory. Such wide departures between theory and experiment are only explicable if we assume either that the nuclei have sensible dimensions or that the inverse square law of repulsion entirely breaks down in such close collisions. If we suppose the complexity in structure and in laws of force is to be ascribed to the α-particle rather than to the hydrogen nucleus, Chadwick and Bieler, as the result of a careful series of experi-

ments, concluded that the α-particle behaved as if it were a perfectly elastic body, spheroidal in shape, with its minor axis at 4×10^{-13} cm. in the direction of motion, and major axis 8×10^{-13} cm. Outside this spheroidal region, the forces fell off according to the ordinary inverse square law, but inside this region the forces increased so rapidly that a particle was reflected from it as from a perfectly elastic body. No doubt such a conception is somewhat artificial, but it does serve to bring out the essential points involved in the collision, *viz.*, that when the nuclei approach within a certain critical distance of each other, forces come into play which vary more rapidly than the inverse square. It is difficult to ascribe this break-down of the law of force merely to the finite size or complexity of the nuclear structure or to its distortion, but the results rather point to the presence of new and unexpected forces which come into play at such small distances. This view has been confirmed by some recent experiments of Bieler in the Cavendish Laboratory in which he has made, by scattering methods, a detailed examination of the law of force in the neighborhood of a light nucleus like that of aluminum. For this purpose he compared the relative number of α-particles scattered within the same angular limit from aluminum and from gold. For the range of angles employed, *viz.*, up to 100°, it is assumed that the scattering of gold follows the inverse square law. He found that the ratio of the scattering in aluminum, compared with that in gold, depended on the velocity of the α-particle. For example, for an α-particle of 3.4 cm. range, the theoretical ratio was obtained for angles of deflection below 40°, but was about 7 per cent. lower for an average angle of deflection of 80°. On the other hand, for swifter particles of range 6.6 cm. a departure from the theoretical ratio was much more marked and amounted to 29 per cent. for an angle of 80°. In order to account for these results he supposes that close to the aluminum nucleus, an attractive force is superimposed on the ordinary repulsive forces. The results agreed best with the assumption that the attractive force varies according to the inverse fourth power of the distance and that the forces of attraction and repulsion balanced at about 3.4×10^{-13} cm. from the nuclear centre. Inside this critical radius, the forces are entirely attractive; outside it, they are repulsive.

While we need not lay too much stress on the accuracy of the

actual value obtained or on the law of attractive force, we shall probably not be far in error in supposing the radius of the aluminum nucleus is not greater than 4×10^{-13} cm. It is of interest to note that the forces between an α-particle and a hydrogen nucleus were found to vary rapidly at about the same distance.

It thus seems clear that the dimensions of the nuclei of light atoms are small, and almost unexpectedly small, in the case of aluminum when we remember that twenty-seven protons and fourteen electrons are concentrated in such a minute region. The view that the forces between nuclei change from repulsion to attraction when they are very close together seems very probable, for otherwise it is exceedingly difficult to understand why a heavy nucleus with a large excess of positive charge can hold together in such a confined region. We shall see that the evidence from various other directions supports such a conception, but it is very unlikely that the attractive forces close to a complex nucleus can be expressed by any simple power law.

RADIO-ACTIVE EVIDENCE.

A study of the long series of transformations which occur in uranium and thorium provides us with a wealth of information on the modes of disintegration of atoms, but unfortunately our theories of nuclear structure are not sufficiently advanced to interpret these data with any detail. The expulsion of high-speed α- and β-particles from the radio-active nucleus gives us some idea of the powerful forces resident in the nucleus, for it can be estimated that the energy of emission of the particle is in some cases greater than the energy that would be acquired if the particle fell freely between two points differing in potential by about four million volts. The energies of the β- and γ-rays are on a similar scale of magnitude.

Notwithstanding our detailed knowledge of the successive transformation of the radio elements, we have not so far been able to obtain any definite idea of their nuclear structure, while the cause of the disintegration is still a complete figure. In comparing the uranium, thorium, and actinium series of transformations, one cannot fail to be struck by the many points of similarity in their modes of disintegration. Not only are the radiations similar in type and in energy, but, in all cases, the end produced is believed to be an isotope of lead. This remarkable similarity in the modes of transformation is especially exemplified

in the case of the "C" bodies, each of which is known to break up in at least two distinct ways, giving rise to branch products. For example, thorium C emits two types of α-rays, 65 per cent. of range 8.6 cm. and 35 per cent. of range 4.8 cm., and in addition some β-rays.

In order to explain these results, it has been suggested that a fraction of the atoms of thorium C break up first with the expulsion of an α-particle and the resulting product then emits a β-particle. The other fraction breaks up in a reverse way, first expelling a β-particle, while the subsequent product emits an α-particle. Similar dual changes occur in radium C and actinium C, although the relative number of atoms in each branch varies widely for the different elements.

This remarkable similarity between the "C" bodies is still further emphasized by the recent discovery of Bates and Rogers that both radium C and thorium C give rise in small numbers to other groups of α-particles, some of them moving at very high speeds.

It has often been a matter of remark that the radio-active properties of the "C" bodies seem to depend more on the atomic number, *i.e.*, the nuclear charge, than on the atomic weight. Confining our attention to radium C and thorium C, which are best known, both have a nuclear charge 83, but the atomic mass of radium C is 214 and of thorium C 212. The nucleus of radium C thus contains two protons and two electrons more than that of thorium C. If it were supposed that the nuclei of these elements consisted of a large number of charged units in ceaseless and irregular motion, it is to be anticipated that the addition of the protons and electrons to the complex structure would entirely alter the nuclear arrangement and consequently its stability and mode of transformation. On the other hand, we find that the modes of transformation of these two nuclei have striking and unexpected points of resemblance which are in entire disaccord with such a supposition. We can, however, suggest a possible explanation of this anomaly by supposing that the α- and β-particles which are liberated from these elements are not built deep into the nuclear structure but exist as *satellites* of a central core which is common to both elements. These satellites, if in motion, may be held in equilibrium by the attractive forces arising from the core and these forces would be the same for both ele-

ments. On this view the manifestations of radio-activity are to be ascribed, not to the main core, but to the satellite distribution, which must be somewhat different for the two elements, although possibly showing many points of similarity. It must be admitted that a theory of this kind is highly speculative, but it does provide a useful working hypothesis, not only to account for the similarity of the modes of transformation of the two elements, but also immediately suggests a possible explanation of the liberation of a number of α-particles of different ranges from the same element. There are two ways of regarding this question. We may in the first place suppose that a certain amount of surplus energy has to be liberated in the disintegration and that this energy may be given to any one of a number of satellites. There will be a certain probability that any particular particle will be given this energy and on this will depend the relative number of particles in the different α-ray groups. The ultimate energy of ejection of an α-particle will depend on its position in the field of force surrounding the inner core at the moment of its liberation. On the other hand, we may suppose that the same α-particle is always ejected but that the particle may occupy in the atom one of a number of "stationary" positions analogous to the "stationary states" of the electrons in Bohr's theory of the outer atom. This rests on the assumption that all the atoms will not be identical in satellite structure, but there will be a number of possible "excited" states of the atom as a consequence of the previous disintegrations. This satellite theory is useful in another connection. It has been suggested that possibly the high-frequency α-rays from a radio-active atom may arise not from the movement of the electrons as ordinarily supposed, but from the transfer of α-particles from one level to another. In such a case, the difference in energies between the various groups of α-particles from radium C and thorium C should be connected by the quantum relation with the frequencies of prominent γ-rays. The evidence at present available is not definite enough to give a final decision on this problem, but points to the need of very accurate measurements of the energies of the various groups of α-particles. On account of the relatively small number of particles in some of the groups, this is difficult of accomplishment.

In considering the satellite theory in connection with the

radio-active bodies, it is at first sight natural to suppose, since the end product of both the radium and thorium series is an isotope of lead, that one of the isotopes of lead forms the central core. It may, however, well be that the radio-active processes cease when there are still a number of satellites remaining. If this be so, the core may be of smaller nuclear charge and mass than that of lead. From some considerations, described later, this core may correspond to an element near platinum of number 77 and mass 192.

FREQUENCY OF VIBRATION OF THE NUCLEUS.

One of the most interesting and important methods of throwing light on nuclear structure is the study of the very penetrating γ-rays expelled by some radio-active bodies. The γ-rays are identical in nature with X-rays, but the most penetrating type of rays consists of waves of much higher frequency than can be produced in an ordinary X-ray tube. The work of the last few years has indicated very clearly that the major part of the γ-radiation from bodies, like radium B and C, originates in the nucleus. A determination of the frequencies of the γ-rays thus gives us direct information on the modes of vibration of parts of the nuclear structure. The frequencies of some of the softer γ-rays excited by radium B and radium C were measured by the crystal method by Rutherford and Andrade, but it is difficult, if not impossible, by this method to determine the frequencies of the very penetrating rays. Fortunately, due largely to the work of Ellis and Fräulein Meitner, a new and powerful method has been devised for this purpose. It is well known that the β-rays from radium B and radium C give a veritable spectrum in a magnetic field showing the presence of a number of groups of β-rays each expelled with a definite speed. It is clear that each of the groups of β-rays arises from conversion of the energy of a γ-ray of definite frequency into a β-ray in one or other of the electronic levels in the outer atom. The energy ω required to move an electron from one of these levels to the outside of the atom is known from a study of X-ray absorption spectra. The frequency ν of the γ-ray is thus given by the quantum relation $h\nu = E + \omega$ where E is the measured energy of the β-particle.

Since each γ-ray may be converted in any one of the known electronic levels in the outer atom, a single γ-ray is responsible for the appearance of a number of groups of β-rays, corresponding to conversion in the K, L, M, etc., levels. In this way, an

analysis of the β-ray spectrum allows us to fix the frequency of the more intense γ-rays which are emitted from the nucleus. The energy of the shortest wave measured in this way by Ellis corresponds to more than two million volts, while other evidence shows that probably still shorter waves are emitted in small quantity from radium C.

Ellis and Skinner have shown that the energies of these rays show certain combination differences, such as are so characteristic of the energies of the X-rays arising from the outer electrons. A series of energy levels may thus be postulated in the nucleus similar in character to the electron levels of the outer atom and the γ-rays have their origin in the fall, either of an electron or of an α-particle between these levels. This is a significant and important result indicating that the quantum dynamics can be applied to the nucleus as well as to the outer electronic structure.

The probability of levels in the nuclear structure is most clearly seen on the satellite hypothesis, but in our ignorance of the laws of force near the core, we are at the moment unable to apply the quantum dynamics directly to the problem. The outlook for further advances in this direction is hopeful but is intimately connected with further development of our knowledge of the laws of force that come into play close to the nucleus in the region occupied by the satellites.

ARTIFICIAL DISINTEGRATION OF ELEMENTS.

We have seen that it is believed that the nuclei of all atoms are composed of protons and electrons and that the number of each of these units in any nucleus can be deduced from its mass and nuclear charge. It is, however, at first sight rather surprising that no evidence of the individual existence of protons in a nucleus is obtained from a study of the transformations of the radio-active elements, where the processes occurring must be supposed to be of a very fundamental character. As far as our observations have gone electrons and helium nuclei, but no protons, are ejected during the long series of transformations of uranium, thorium and actinium. One of the most obvious methods for determining the structure of a nucleus is to find a method of disintegrating it into its component parts. This is done spontaneously for us by nature to a limited extent in the case of the heavy radio-active elements, but evidence of this character is not available in the case of the ordinary elements. As

the swift α-particle from the radio-active bodies is, by far, the most energetic projectile known to us, it seemed from the first possible that occasionally the nucleus of a light atom might be disintegrated as the result of a close collision with an α-particle. On account of the minute size of the nucleus, it is to be anticipated that the chance of a direct hit would be very small and that consequently the disintegration effects, if any, would be observed only on a very minute scale. During the last few years, Doctor Chadwick and I have obtained definite evidence that hydrogen nuclei or protons can be removed by bombardment of α-particles from the elements boron, nitrogen, fluorine, sodium, aluminum, and phosphorus. In these experiments, the presence of H nuclei is detected by the scintillation method and their maximum velocity of ejection can be estimated from the thickness of matter which can be penetrated by these particles. The number of H nuclei ejected, even in the most favorable case, is relatively very small compared with the number of bombarding α-particles, *viz.*, about one in a million.

In these experiments the material subject to bombardment was placed immediately in front of the source of α-particles and observations on the ejected particles were made on a zinc sulphide screen placed in a direct line a few centimetres away. Using radium C as a source of α-rays, the ranges of penetration expressed in terms of centimetres of air were in all these cases greater than the range of free nuclei (30 cm. in air) set in motion in hydrogen by the α-particles. By inserting absorbing screens of 30 cm. air equivalent in front of the zinc sulphide screen, the results were quite independent of the presence of either free or combined hydrogen as an impurity in the bombarded materials. Some of the lighter elements were examined for absorptions less than this but, in general, the number of H-particles due to hydrogen contamination of the source and the materials was so large that no confidence could be placed in the results.

In such experiments many scintillations can be observed, but it is very difficult to decide whether these can be ascribed in part to an actual disintegration of the material under examination. The presence of long-range particles of the α-ray type from the source of radium C still further complicates the question, since in general the number of such particles is large compared with the disintegration effect we usually observe.

To overcome these difficulties, inherent in the direct method of observation, Doctor Chadwick and I have devised a simple method by which we can observe with certainty the disintegration of an element when the ejected particles have a range of only 7 cm. in air. This method is based on the assumption, verified in our previous experiments, that the disintegration particles are emitted in all directions relative to the incident rays. A powerful beam of α-rays falls on the material to be examined and the liberated particles are observed at an average angle of 90° to the direction of the incident α-particles. By means of screens it is arranged that no α-particles can fall directly on the zinc sulphide screen.

This method has many advantages. We can now detect particles of range more than 7 cm., with the same certainty as particles of range above 30 cm., in our previous experiments, for the presence of hydrogen in the bombarded material has no effect. This can be shown at once by bombarding a screen of paraffin wax, when no particles are observed on the zinc sulphide screen. On account of the very great reduction in number of H nuclei or α-particles by scattering through 90°, the results are quite independent of H nuclei from the source or of the long-range α-particles. The latter are just detectable under our experimental conditions when a heavy element like gold is used as scattering material, but are inappreciable for the lighter elements.

A slight modification of the arrangement enables us to examine gases as well as solids.

Working in this way we have found that in addition to the elements boron, nitrogen, fluorine, sodium, aluminum, and phosphorus, which give H particles of maximum range in the forward direction between 40 and 90 cm., the following give particles of range above 7 cm., neon, magnesium, silicon, sulphur, chlorine, argon, and potassium. The numbers of the particles emitted from these elements are small compared with the number from aluminum under the same conditions, varying between 1/3 and 1/20. The ranges of the particles have not been determined with accuracy. Neon appears to give the shortest range, about 16 cm., under our conditions, the ranges of the others lying between 18 cm. and 30 cm. By the kindness of Doctor Rosenhain we were able to make experiments with a sheet of metallic beryllium. This gave a small effect about 1/30 of that of aluminum, but we are

not yet certain that it may not be due to the presence of a small quantity of fluorine as an impurity. The other light elements, hydrogen, helium, lithium, carbon, and oxygen give no detectable effect beyond 7 cm. It is of interest to note that while carbon and oxygen give no effect, sulphur, also probably a "pure" element of mass 4n, gives an effect of nearly 1/3 that of aluminum. This shows clearly that the sulphur nucleus is not built up solely of helium nuclei, a conclusion also suggested by its atomic weight of 32.07.

We have made a preliminary examination of the elements from calcium to iron, but with no definite results, owing to the difficulty of obtaining these elements free from any of the "active" elements, in particular, nitrogen. For example, while a piece of electrolytic iron gave no particles beyond 7 cm., a piece of Swedish iron gave a large effect which was undoubtedly due to the presence of nitrogen, for after prolonged heating *in vacuo* the greater part disappeared. Similar results were experienced with the other elements in this region.

We have observed no effects from the following elements, nickel, copper, zinc, selenium, krypton, molybdenum, palladium, silver, tin, xenon, gold and uranium. The krypton and xenon were kindly lent by Doctor Aston.

EXAMINATION OF LIGHT ELEMENTS FOR PARTICLES OF RANGE LESS THAN 3 CM. OF AIR.

When α-particles are scattered from light elements, the simple theory shows that the velocity of the scattered particles depends on the angle of scattering. For example, using bombarding α-particles of range 7 cm., the range of the α-particles scattered through more than 90° cannot be greater than 1.0 cm. for lithium (7); 2.0 cm. for beryllium (10); 2.5 cm. for carbon; 3.2 cm. for oxygen; 4.3 cm. for aluminum, and 6.8 cm. for gold.

Provided we introduce sufficient thickness of absorber to stop the particles scattered through 90°, we can examine for disintegrated particles from carbon, for example, whose range exceeds 2.5 cm. Certain difficulties arise in this type of experiment which are absent when the thickness of absorber is greater than 7 cm.; any heavy element present as an impurity will give scattered α-particles of range greater than those from carbon and thus complicate the observations. In addition, serious troubles may arise due to the volatilization or escape of active matter from

the source. This is especially marked if the vessel containing the radio-active source is exhausted. To overcome this difficulty, we have found it desirable to cover the source with a thin layer of celluloid of 2 or 3 mm. stopping power for α-rays. By this procedure, we have been able to avoid serious contamination and to examine the lighter elements by this method. We have been unable to detect any appreciable number of particles from lithium or carbon for ranges greater than 3 cm. If carbon shows any effect at all, it is certainly less than one-tenth of the number from aluminum under the same conditions. This is in entire disagreement with the work of Kirsch and Patterson,[1] who found evidence of a large number of particles from carbon of range 6 cm. A slight effect was observed in beryllium in accordance with our other experiments. No effect was noted in oxygen gas. Apart from beryllium, no certain effect has been noted for elements lighter than boron.

Under the conditions of our experiment, it seems clear that neither H nuclei nor other particles of range greater than 3 cm. can be liberated in appreciable numbers from these elements in a direction at right angles to the bombarding α-rays. This is, in a sense, a disappointing result for, unless these elements are very firmly bound structures, it was to be anticipated that an α-particle bombardment would resolve them into their constituent particles.

We hope to examine this whole question still more thoroughly, as it is a matter of great importance to the theory of nuclear constitution to be certain whether or not the light elements can be discharged by swift α-particles.

In considering the results of our new and old observations, some points of striking interest emerge. In the first place, all the elements from fluorine to potassium, inclusive, suffer disintegration under α-ray bombardment. As far as our observations have gone, there seems little doubt that the particles ejected from all these elements are H nuclei. The odd elements B, N, Fl, Na, Al, P, all give long-range particles varying in range from 40 cm. to 90 cm. in the forward direction, the even elements C, O, Ne, Mg, Si, S, either give few or none at all as in the case of C and O, or give particles of much less range than the adjacent odd-numbered elements. The difference between the range of even

[1] *Nature*, April 26, 1924.

odd elements becomes much less marked for elements heavier than phosphorus.

This obvious difference in velocity of expulsion of the H nuclei from even and odd elements is a matter of great interest. Such a distinction can be parallelled by other observations of an entirely different character. Harkins has shown that elements of even atomic number are much more abundant in the earth's crust than elements of odd atomic number. In his study of isotopes, Aston has shown that in general odd-numbered elements have only two isotopes differing in mass by two units, while even-numbered elements in some cases contain a large number of isotopes. This remarkable distinction between even and odd elements cannot but excite a lively curiosity, but we can at present only speculate on its underlying cause.

VELOCITY OF ESCAPE OF HYDROGEN NUCLEI.

We have seen that the experiments of Bieler on the scattering of X-rays by aluminum and magnesium indicate that a powerful attractive force comes into play very close to the nuclei of these atoms. If this be the case, the forces of attraction and repulsion must balance at a certain distance from the nucleus. Outside this critical point the forces on a positively charged body are entirely repulsive. Certain important consequences follow from this general view of nuclear forces. Suppose, for example, that, due to a collision with a swift α-particle, a hydrogen nucleus is liberated from the nuclear structure. After passing across the critical surface, it will acquire energy in passing through the repulsive field. It is clear, on this view, that the energy of a charged particle after escape from the atom cannot be less than the energy acquired in the repulsive field; consequently we should expect to find evidence that there is a minimum velocity of escape of a disintegration particle. We have obtained definite evidence of such an effect both in aluminum and sulphur by examining the absorption of H nuclei from these elements. The number of scintillations for a thin film was found to be nearly constant for absorption between 7 and 12 cm., but falls off rapidly for greater thickness. This is exactly what is to be expected on the views outlined. No doubt the limiting velocity varies somewhat for the different elements, but a large amount of experiment will be required to fix this limit with accuracy. From these results, it is possible to form a rough estimate of the potential of the field at

the critical surface and this comes out to be about three million volts for aluminum. The value for sulphur is somewhat greater. This brings out in a striking way the extraordinary smallness of the nuclei of these elements, for it can be calculated that the critical surface cannot be distant more than 6×10^{-13} cm. from the centre of the nucleus. These deductions of the critical distance are in excellent accord with those made by Bieler from observations of the scattering of α-particles.

Another important consequence follows. It is clear that an α-particle fired at the nucleus will not be able to cross this critical surface and thus be in a position to produce disintegration, unless its velocity exceeds that corresponding to the critical potential. In an experiment made a few years ago, we found that the number of H nuclei liberated from aluminum fell off rapidly with diminution of the velocity of the α-particle and was too small in number to be detected when the range of the α-particle was less than 4.9 cm. This corresponds to the energy of an α-particle falling between about three million volts—a value in good accord with that calculated from the escape of H nuclei.

Further experiments are required with other elements to test if this relation between the minimum velocity of H nuclei and the minimum velocity of the α-particle to produce disintegration holds generally; but the results as far as they go are certainly very suggestive.

It is of interest to note that these results afford a definite proof of the nuclear conception of the atom and gives us hope that we may determine the magnitude of the critical potential for a number of the light elements.

EVOLUTION OF NUCLEI.

In concluding, I would like to make a few remarks of a more speculative character dealing with the fundamental problem of the origin and evolution of the elements from the two fundamental building units, the positive and negative electrons. It must be confessed that there is little information to guide us with the exception of our knowledge of the nuclear charges and masses of the various species of elements which survive to-day. It has always been a matter of great difficulty to imagine how the more complex nuclei can be built up by the successive additions of protons and electrons since the proton must be endowed with a very high speed to approach closely to the charged nucleus. I have already discussed

in this paper the evidence that powerful attractive forces varying very rapidly with the distance are present close to the nuclear structure, and it seems probable that these forces must ultimately be ascribed to the constituent proton. In such a case, it may be possible for an electron and proton to form a very close combination, or neutron, as I have termed it. The probable distance between the centre of this doublet is of the order of 3×10^{-13} cm. The forces between the two neutrons would be very small except for distance of approach of this order of magnitude, and it is probable that the neutrons would collect together in much the same fashion as a number of small movable magnets would tend to form a coherent group held together by their mutual forces.

In considering the origin of the elements, we may for simplicity suppose a large diffused mass of hydrogen which is gradually heated by its gravitational condensation. At high temperatures, the gas would consist mainly of free hydrogen nuclei and electrons and some of these would in course of time combine to form neutrons emitting energy in the process. These neutrons would collect together in nuclear masses of all kinds of complexity. Now the tendency of the groups of neutrons would be to form more stable nuclear combinations, such as helium nuclei of mass four, and possibly intermediate stages of masses two and three. Energy would be emitted in these processes probably in the form of swift surplus electrons which were not necessary for the stability of the system. In a sense, all these nuclear masses would be radio-active, but some of them in their transformation may reach a stable configuration which would represent the nucleus of one of our surviving elements. If we suppose that nuclear masses over a wide range of mass can be formed before serious transformation occurs, it is easy to see how every possible type of stable element will gradually emerge. If we take the helium nucleus as a combining unit which emits in its formation the greatest amount of energy, we should ultimately expect many of the neutrons in a heavy nucleus to form helium nuclei. These helium nuclei would tend to collect together and form definite systems, and it seems not unlikely that they will group themselves into orderly structures, analogous in some respects to the regular arrangement of atoms to form crystals, but with much smaller distances between the structural units. In such a case, some of the elements may consist of a central crystal type of structure of helium nuclei surrounded by

positively and negatively charged satellites in motion round this central core. Assuming that such orderly arrangements of helium nuclei are possible, it is of interest to note that the observed relations between atomic charges and atomic mass for the elements can be approximately obtained on a very simple assumption. Suppose that helium nuclei form a point-centred cubic lattice with an electron at the centre of a crystal unit of eight helium nuclei. A few of the possible types of grouping are given in the following table with corresponding masses and nuclear charges. The structure "4. 3. 2." means a rectangular arrangement with sides containing 4. 3. 2. nuclei, respectively. It will thus contain twenty-four helium nuclei, have a mass 96, and will contain six intranuclear electrons. Its nuclear charge will therefore be $48 - 6 = 42$.

Structural Arrangement of Helium Nuclei.	Calculated Nuclear Charge.	Calculated Mass.	Known Element of Equal Charge.
3. 2. 2.	22	48	Ti 48
3. 3. 2.	32	72	Ge 74, 72, 70
3. 3. 3.	46	108	Pa 106.7
4. 2. 2.	29	64	Cu 63.35
4. 3. 2.	42	96	Mo 96
4. 3. 3.	60	144	Nd 144
4. 4. 3.	78	192	Pt 195

While the agreement is far from perfect for all these structures, there is a general accord with observation. If we take the view that some of these structures can grow by the addition of satellites, there is room for adjustment of masses and to include the intervening elements. This point of view is admittedly very speculative and there may well be other types of structure involved. At the same time the general evidence suggests that there are some basal structures on which the heavier atoms are progressively built up. The failure of the whole number rule for the mass of isotopes, observed in some cases by Aston, *e.g.*, between tin and xenon, certainly supports such a conception. From a study of the artificial disintegration of the elements we have seen that carbon and oxygen represent very stable structures probably composed of helium nuclei. It is possible that oxygen nuclei, for example, may be the structural basis of some of the elements following oxygen, but our information is at present too meagre to be at all certain on this point.

I think, however, it will be clear from this lecture that a difficult but fascinating problem is involved in the structure of nuclei. Before we can hope to make much advance, it is essential to know more of the nature of the forces operative close to protons and electrons and we may hope to acquire much information by a detailed study of the scattering of swift α-rays and β-rays by nuclei. Fortunately, there are now a number of distinct lines of attack in this problem, and from a combination of the results obtained, we may hope to make steady, if not rapid, progress in the solution of this, the greatest problem in physics.

The Production of Very Intense Magnetic Fields. T. F. WALL. (*Nature*, Sept. 20, 1924.)—When condensers of 700 microfarads capacity, charged to a difference of potential of 1850 volts, were discharged through a magnetizing solenoid having 25.5 turns per centimetre, the oscillograph record gave 12,500 amperes for the current strength at the first peak of the discharge. "This means that an intensity of magnetic field of about 400,000 gauss was generated. By means of a modification of the apparatus which is now being effected, it is expected that an intensity of magnetic field of about 1,500,000 gauss will be obtained very shortly." G. F. S.

IN A joint paper by Friend, Hammond and Trobridge, of the Municipal Technical School of Birmingham, England, the effects of emulsoids or protective colloids on the rate of corrosion of iron were studied with care. The results were presented at the Forty-sixth General Meeting of the American Electrochemical Society in October, 1924. The retarding influence is due to adsorption of the emulsoid. The authors suggest a method of treating waters to diminish their corrosive action on metals and alloys. The experiments were conducted by suspending small plates of steel in solutions of lead acetate, to which measured quantities of agar were added. Increased quantities of agar resulted in the proportionate retardation of corrosion. Other experiments were made with steel plates in a solution of copper sulphate with the addition of certain emulsoids in small amount. Here again a pronounced retarding influence was observed. The presence of precipitated copper on the surface of the metal affords little protection. As might be expected the corrosion increased with the temperature. If the plates are kept in motion the protective effect of the emulsoids is very much diminished. Iron cooking utensils resist corrosion very well when used in the preparation of food. This is just what would be expected from other data in this field and may be said to be due substantially to the buffer effect of the organic matters. H. L.

TWENTY-FIVE YEARS' PROGRESS IN EXPLOSIVES.*

BY

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Member of the Institute.

THE subject of my address is so very broad that I feel it should be modified to read "Twenty-five Years' Progress in High Explosives in America," and so I have confined myself in this way, only referring to European developments when it is necessary to do so to tie them together where they have a bearing on one another.

BLACK POWDER.

Black powder, the forerunner of all modern explosives, has undergone little or no change in composition for many years except the substitution of sodium nitrate for potassium nitrate in blasting powders in this country, and the short-lived brown prismatic military powder, made with only partially carbonized wood charcoal and pressed into perforated grains at high pressure to prevent its too rapid combustion in the gun. This powder received its death knell at the time of the Spanish-American War due to the perfection, or rather the introduction, of nitrocellulose smokeless powder for military purposes.

Although it was thought that the introduction of nitroglycerine dynamite would displace black powder, it has not reduced the production, but has to a large extent prevented material increase.

Numerous attempts have been made to evolve new processes for the manufacture of black powder, but none has resulted in material change from the ancient practice except as regards modifications in design and construction of apparatus and machinery.

One notable case was an attempt to manufacture blasting and sporting powder by a continuous automatic process which involved the wet mixing and incorporation of the sulphur, nitrate, and charcoal, partial drying, and pressing into grains on revolving drums, drying on a continuous belt and glazing. It was even proposed to place this machinery on railroad cars so that the non-explosive ingredients could be carried on the train and the

* Address delivered Friday, September 19, 1924, on the occasion of the observance of the centenary of the founding of The Franklin Institute.

explosive manufactured at the point of delivery, thus avoiding the dangers of transportation. Several hundred thousand dollars were spent on this process and good powder was produced, but the process had to be finally abandoned as uneconomical.

DYNAMITE.

Up to 1900 fairly rapid progress had been made in the manufacture and formulation of nitroglycerine high explosives, but there was very little literature at that time on the technology of high explosives, with the exception of Berthelot, dealing with the theory, and Guttman, who dealt mostly with the manufacture of the ingredients, and two misleading and much out-of-date dictionaries of explosives.

To the layman and most professors of chemistry at that time, dynamite was a mixture of nitroglycerine and infusorial earth, whereas the latter inert material had been replaced for many years, in this country at least, by a properly balanced active mixture of wood pulp and sodium nitrate. The use of infusorial earth as an absorbent was extremely wasteful, for it has been determined that each per cent. of inert material in dynamite is equivalent to reducing the percentage of nitroglycerine by 1 per cent., for example, 10 per cent. of inert material will reduce a 60 per cent. dynamite to the equivalent of a 50 per cent. dynamite.

It might be interesting to mention the fact that it became necessary for American manufacturers of active base dynamites to color them with red oxide of iron for the Mexican trade, which was accustomed to the naturally red " guhr " dynamites sold them by European manufacturers.

At the beginning of the present century, there were in use three general classes of high explosives containing nitroglycerine:

(1*a*) Straight nitroglycerine powder, containing varying percentages from 60 per cent. down to 20 per cent. of nitroglycerine, the necessary amount of wood pulp to hold the nitroglycerine and prevent leakage, and the chemical equivalent of sodium or potassium nitrate to take care of the wood pulp, the paper wrapping and water-proofing paraffin, and to maintain the proper oxygen balance.

(1*b*) The Judson powder type, which consisted of a dope made by mixing ground coal with sodium

nitrate and sulphur at temperatures above the melting point of sulphur, thus forming hard grains which were screened to size and coated with from 5 per cent. to 15 per cent. nitroglycerine. This formed an explosive, intermediate between black powder and regular dynamite, and was used largely for moving earth and soft rock in railroad work.

(2) Blasting gelatine and the so-called gelatine powders containing enough special nitrocellulose to make a fairly stiff colloid with the nitroglycerine. These powders were made in varying strengths from blasting gelatine to gelatine dynamites of 35 per cent.

(3) The so-called ammonia dynamites and gelatines in which some of the nitroglycerine is replaced by ammonium nitrate.

I might mention the Sprengle type represented by Rackarock, which consisted of cartridges made of potassium chlorate, which were dipped in nitrobenzene just before using, and which was used with great success in the removal of the rock at Hell Gate in the New York Harbor. This powder disappeared from the market entirely, but was retained as a standard explosive, for demolition purposes, by the United States Army up to the time of the European War, when it was replaced by trinitrotoluol compressed into blocks and electroplated with copper to protect them in handling.

NITROGLYCERINE.

In 1923 the records of the Bureau of Explosives show that 530 million pounds of explosives were produced and distributed in this country, of which 330 million pounds were high explosives. This would mean that about 100 million pounds of nitroglycerine were produced, or fifty thousand tons. With an enormous production such as this, the question of yields, based on glycerine and nitric acid used, becomes an important one.

Since the nitration takes place readily under conditions which prevent oxidation, that is, at sufficiently low temperatures, the yields should be practically theoretical on the pure glycerine used were it not for the solubility of the ester in the waste acid and in the wash waters.

Nitroglycerine yields are stated in the art as so many pounds per 100 pounds of glycerine, and in the nineties a yield of 215 to 220, 88.9 per cent. to 91.1 per cent. based on 98 per cent. glycerine, was considered very good. An increase of about five points was brought about by Lawrence, who lowered the solubility in waste acid by cooling the latter, after separation, down below the freezing point of nitroglycerine.

With the advent of fuming sulphuric acid in 1901, it seemed likely that its use would bring about much improvement in the manufacture of nitroglycerine. However, owing to the extreme and proper conservatism of manufacturers of this dangerous material, it took much time and experiment, both in the laboratory and on a semi-works scale, to determine the best and safest ratios of nitric acid, sulphuric acid and glycerine, and, what is also very important, the best ratio of sulphuric acid to water in the mixture plus the water of reaction, to bring about such improvements as are represented by yields of 233 to 235 with much reduced consumption of nitric acid. The higher yields are largely due to reduction in the ratio of waste acid to nitroglycerine and the higher acidity of the former, rendering the nitroglycerine less soluble.

Such yields with 98 per cent. glycerine are 96.4 per cent. to 97.2 per cent. of the theoretical, and when we consider the solubility of nitroglycerine in waste acid and wash waters, they are practically theoretical. Still higher yields can be obtained with higher consumption of nitric acid, but this is controlled by the relative costs of the two ingredients. Eleven points in yield mean a saving to the industry, and to the customer as well, of $750,000 to $1,000,000 per year.

SEPARATION OF NITROGLYCERINE.

Much difficulty was experienced in the separation of nitroglycerine from the waste acids, especially with certain brands of glycerine, sometimes taking as much as two hours, whereas the process of nitration took about an hour, so that as a matter of economy as well as safety it was very desirable to discover a means of hastening the separation.

In 1902–1903 a long painstaking study disclosed the presence of gelatinous or colloidal silica (SiO_2) in the sludge obtained in the purification process which was traced back to the glycerine. Hydrofluoric acid naturally suggests itself in connection with

SiO_2 and consequently it was found that a small, almost catalytic, dose of sodium fluoride added to the charge, brought about the desired effect, so that separations are now frequently completed in fifteen minutes, and the nitroglycerine is purified and in storage long before the next charge is ready.

It was later learned that a normal separation of about one hour with glycerine free from colloidal silica could be hastened by the addition of small amounts of water-glass or other forms of silica, such as infusorial earth and later addition of sodium fluoride.

In the case of glycerine containing colloidal silica in the form of a glycerogel or a soluble silica, it was thought that the hydrofluoric acid formed when the fluoride came in contact with the acid, set free silicon tetrafluoride, and thus the emulsion was broken and the rising gas assisted the movement of the globules of nitroglycerine.

The addition of water-glass to the glycerine will practically make a permanent emulsion of the nitroglycerine, but the fluoride breaks this almost immediately. The study of the true cause of this phenomenon would make an interesting subject for investigation. (U. S. Patent 804,817, November 14, 1905, to C. L. Reese.)

LOW-FREEZING AND NON-FREEZING EXPLOSIVES.

The freezing point of nitroglycerine for many years was held to be about 12.8° C. (55° F.), but in 1906 Kast announced the discovery of an isomeric form of solid nitroglycerine melting at 2.8°. In 1911 Nauckhoff attempted to produce this lower freezing form but failed.

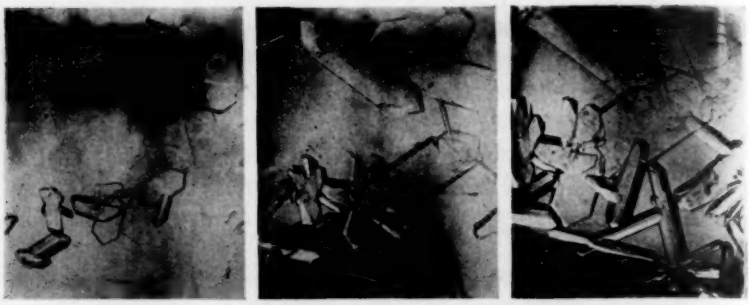
With a view to the possibility of utilizing materials in the powder formulæ which would only produce the lower freezing form of nitroglycerine, a careful study of the subject was carried out in our laboratory by Harold Hibbert, and the results published in the proceedings of the Eighth International Congress of Applied Chemistry in 1912, and also in the *Journal of the American Chemical Society* (Vol. xxxv, 978, 1913).

The results of this work definitely established the existence of two solid forms of nitroglycerine, a labile and a stable physical isomeride having melting points of 2° C. and 13.2° C., respectively. The methods of production and the properties of both were established and microphotographs made (Figs. 1 and 2). The lower melting forms could be produced by supercooling

nitroglycerine in mixture with wood pulp, but the higher was always produced in mixture with wood pulp and nitrate of soda, so that although the work proved to be of no practical value it is of much scientific interest.

Although commercial nitroglycerine, with a freezing point

FIG. 1.



Stable form of nitroglycerine. Melting point 13.2° centigrade. Showing progressive growth of crystals.

of about 12.8° C., will usually stand considerable supercooling, and owing to the great danger and many serious accidents which have resulted from handling and thawing frozen dynamite, the problem of producing low-freezing or preferably non-freezing

FIG. 2.

Labile form of nitroglycerine. Melting point 2° centigrade.

dynamites was one of the most important before us, not only from a business, but from a humanitarian point of view.

The thawing of dynamite was always necessary before it could be used in cold weather and many devices were resorted to for this purpose. A frozen stick of dynamite is liable to explode when broken in two, probably from internal friction between the crystals.

The obvious method of reducing freezing point is to dissolve some substances in the liquid, and in our search for such a substance nitro bodies with some explosive potential naturally suggested themselves. Mono- and di-nitro naphthalene were tried without success owing to the high oxygen deficiency of these substances. Tri- and tetra-nitro naphthalene were also made, but were too costly, owing to the easy oxidizability of the naphthalene radical to phthalic acid. The liquid isomers of 2. 4. 6. trinitrotoluene, a by-product of the manufacture of that body, proved to be very useful in reducing the freezing point of nitroglycerine, and a class of low-freezing dynamites and ammonia dynamites were manufactured and introduced about 1907. The explosives contained about 20 to 25 parts of the liquid dissolved in nitroglycerine and froze around 30° F. (below 0° C.).

The limited supply of this material, which was at that time secured from England, made it necessary to seek a substitute, which we obtained by direct nitration of toluene to a mixture of mono-, di-, and tri-nitro toluol having a nitrogen content of about 14 per cent. and which should remain liquid. Large quantities of toluol were used in this, but some difficulty was met with in the tendency of the dinitro body to crystallize out before use.

To overcome this difficulty and to secure a cheaper raw material, a method was developed to nitrate and purify commercial solvent naphtha, which consisted at that time principally of xylene, toluene, and some mestylene. This nitrated mixture contained also about 14 per cent. nitrogen and was used for some time, but was later somewhat modified by the addition of small quantities of naphthalene to the nitrating mixture to prevent some solidification in cold weather in the dynamite mixing house. Although many millions of pounds of low-freezing powders, which contained these mixtures and which were satisfactory to the trade, were sold and used, they were not entirely satisfactory on account of odor and staining of the cartridge wrappers, so that after the manufacture of trinitrotoluene had been established, and cost reduced sufficiently by tonnage manufacture, it was decided to use this explosive in the place of the former mixture.

This was also more satisfactory because of its higher potential strength. The use of this material in low-freezing explosives continued up to the beginning of the world war, when it became necessary to conserve all toluol for military purposes.

In 1911 nitrated mixtures of glycerine and sugar, mixed with T.N.T. (Woodbury, U. S. Patent 1,149,487), were introduced. Though the calculated freezing point of this new liquid mixture was not much lower than the ones previously used, dynamite containing the same showed very marked resistance to freezing, even at temperatures below 0° F. These explosives have been used very extensively throughout this country, but as far as I know have never been introduced in Europe. A low-freezing dynamite was manufactured in Germany for a time, in which di-nitro-chlor-hydrin was used, but the manufacture of this material never appealed to me owing to the liberation of chlorine during nitration.

The methods of producing low-freezing dynamites which I have already referred to were never applied to so-called safety or permissible explosives, nor to gelatine dynamites. The first low-freezing dynamites of these classes were developed during the years 1911 and 1912 as a result of a long study on the condensation or polymerization of glycerine and nitration of the polymers. A method for condensation of glycerine worked out in our laboratory by S. H. Fleming (U. S. Patent 978,443, 1910) consists of heating dynamite glycerine to about 230° C. to 250° C. in the presence of ½ per cent. to 1 per cent. of sodium acetate under a partial vacuum of 150 to 250 mm. of mercury. In this way 70 per cent. to 80 per cent. of the glycerine is condensed to di-glycerine in less than one hour—$C_3H_5(OH)_2$–O–$C_3H_5(OH)_2$ (glyceryl ether).

By other methods which have been described in the literature there is danger of decomposition products being formed and further condensation to tri- and tetra-glycerine which would probably be too viscous to handle.

Di-glycerine, or glyceryl ether, when nitrated produces tetra-nitro-di-glycerine with nearly 16 per cent. nitrogen content as against 18.6 per cent. for nitroglycerine. In order not to reduce the potential too much, a mixture of tri-nitroglycerine and tetra-nitro-di-glycerine is used, and this can be accomplished either by regulating the degree of polymerization or by adding glycerine to the highly polymerized material.

It is well known that viscous liquids which become more viscous on cooling, though they might have a relatively high freezing point, are very often difficult to freeze, that is, they may

be easily supercooled without solidification. This is true of highly concentrated glycerine which, even in cold climate, is ordinarily stored out of doors in steel drums. Occasionally, due to some shock or other condition, a drum of glycerine will freeze, and when once frozen it is equally difficult to thaw, and on two occasions, many years apart, I have known a workman, on failing to get glycerine from a drum through an inserted stopcock, to cause a large number to freeze by seeding them with a crystal by trying the other drums with the same cock. The melting point of glycerine is about 17° C. or 62.6° F.

Tetra-nitro-di-glycerine is much more viscous than nitroglycerine and consequently much more difficult to freeze and when dissolved in nitroglycerine the freezing point is consequently lowered.

We have succeeded in freezing the nitrated mixture at extremely low temperatures, but have never succeeded in freezing dynamites in which it is used, even under storage throughout the very low temperatures experienced in the Northwest. This composition has enabled us to manufacture all classes of nitroglycerine explosives, including the so-called straight, gelatine, ammonia and permissibles which are practically non-freezable and consequently the dangerous operation of thawing dynamites has been done away with.

PERMISSIBLE EXPLOSIVES.

Many disastrous explosions and much loss of human life have occurred in gaseous and dusty coal mines which resulted early in the nineteenth century in the invention by Sir Humphry Davy of his safety lamp which proved to be such a boon to the miners of coal.

There was little hope of overcoming the danger due to the use of explosives in such mines as long as black powder was the only available one to be used. Many mechanical and chemical devices were invented to take the place of explosives, but none was satisfactory. In 1885 the German Government took the matter in hand and research has been carried on not only there, but in England, France, Belgium and other countries ever since, to produce explosives safe for use in coal mines.

It was my privilege, when the Eastern Laboratory of the du Pont Company was established in 1902, to be able to attack this problem, as there had been nothing done up to that time to

develop such satisfactory explosives in the United States except for the sale of a few lots of so-called " Flameless Powders " built on some early but unsatisfactory formulæ, depending upon the use of ammonium sulphate and alum in rather large proportions, depending upon the water of crystallization in the latter to keep the temperature of combustion down as low as possible.

All possible information was secured from Germany and other European countries, and particularly the apparatus developed by Bichel, Schmidt, and Mettegang, including the pressure gauge, calorimeter, apparatus for velocity of detonation and for photographing and measuring the lengths and duration of the flames were installed in 1904. With this equipment installed we were the pioneers in attacking this highly important humanitarian problem in this country. In order to get such explosives in the hands of the miners, we selected out of thirty odd formulæ, the best powder which had been developed in Europe at that time as established by our own studies, namely, the German carbonites and the English monobels.

The carbonite class were low-grade dynamites containing 25 per cent. to 30 per cent. nitroglycerine with 20 per cent. to 40 per cent. meal and potassium or sodium nitrate. The English monobels contained 10 per cent. nitroglycerine, 80 per cent. ammonium nitrate and 10 per cent. wood meal.

The safety of explosives in coal mines is dependent upon a number of factors and primarily among them is the length and duration of the flame produced by a given amount of the explosive. Other qualities are the pressure developed, the strength, the velocity of detonation, and the heat and temperature developed.

With detonating explosives the safety is generally in inverse ratio to the degree of these qualities, but with black blasting powder the danger with gas and coal dust is mostly due to the length and duration of the flame, and the other qualities are low in comparison with most so-called permissible explosives.

The relation of these qualities of explosives to safety in coal mines is thoroughly discussed in Heize's book, and the apparatus for their determination is fully described in Bulletin No. 15 of the Bureau of Mines, published in 1912.

In 1909, the U. S. Geological Survey, through the efforts of the late Dr. Joseph H. Holmes, established the Pittsburgh testing station for determining the safety of commercial explosives,

and they established standards, which such explosives should meet, to be put on their so-called "permissible list" for use in gaseous and dusty coal mines. This station was taken over by the Bureau of Mines on July 1, 1910.

The carbonites and monobels were put on the permissible list as soon as they could be tested at Pittsburgh prior to March, 1909. The safety of the carbonite class is dependent upon their high carbon and moisture content in comparison with their oxygen content and consequent low temperature of explosion. The safety of the monobel class is due largely to their high ammonium nitrate content and consequent low temperature of combustion.

However, I will not go into the thermochemical considerations, as they have been so ably handled by Walter O. Snelling in his "Thermochemistry of Explosives" in Bulletin No. 15, to which I have referred.

According to the permissible list published in 1923, of 154 permissible explosives, 110 are of the ammonium nitrate or monobel class, and only thirty-two are of the carbonite class, twelve belonging to the miscellaneous classes.

Early in 1909 a testing gallery was installed so that we were then equipped with all the necessary apparatus for studying such explosives. Due to the fact that the users soon showed their preference for the monobel nitrate of ammonia type, work was soon discontinued on the carbonite type.

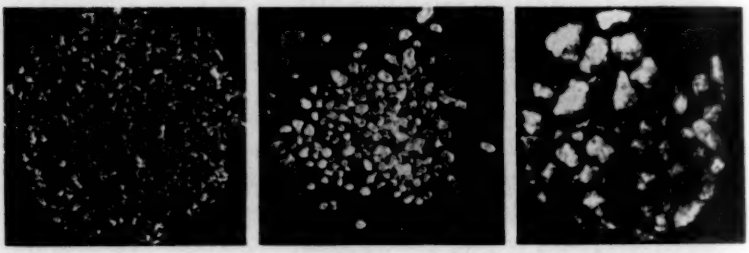
In 1910 it was discovered that by the substitution of 10 per cent. of sodium chloride for an equivalent amount of ammonium nitrate in the monobels, safer and larger charges could be used. This, however, resulted in reducing the strength and, in 1911, it was discovered that relatively small amounts of sodium nitrate had the effect of reducing the tendency of ammonium nitrate explosives to ignite gas or dust, and that the use of this material in percentages of from 3 to 5 in the place of sodium chloride greatly increased the strength.

The mere statement of the chemical formula of an explosive is not always sufficient to enable even the experienced manufacturer to produce a satisfactory product, for much depends upon the physical characteristics of the ingredients, their moisture content, and in some cases the properties of the raw materials from which they are made, for instance, the cellulose from which nitrocellulose

is made for the manufacture of gelatine dynamite must have special treatment to make the nitrate derived from it uniformly suitable for this purpose.

The velocity of detonation of nitrate of ammonia explosives may be varied by the physical character of the nitrate grains, thus a slow powder for producing lump coal is made with a coarse hard-grained nitrate, whereas a powder for the production of coking coal requires a fine-grained nitrate. Density of packing in the cartridge also affects the qualities of the powder. The character of the absorbent or combustible material may also be varied so that it is now possible to make a number of grades

FIG. 3.



Fine, medium and coarse granulations of ammonium nitrate, used to regulate velocity of detonation.

of the same explosive by simply varying the physical characteristics of the ingredients and density of packing.

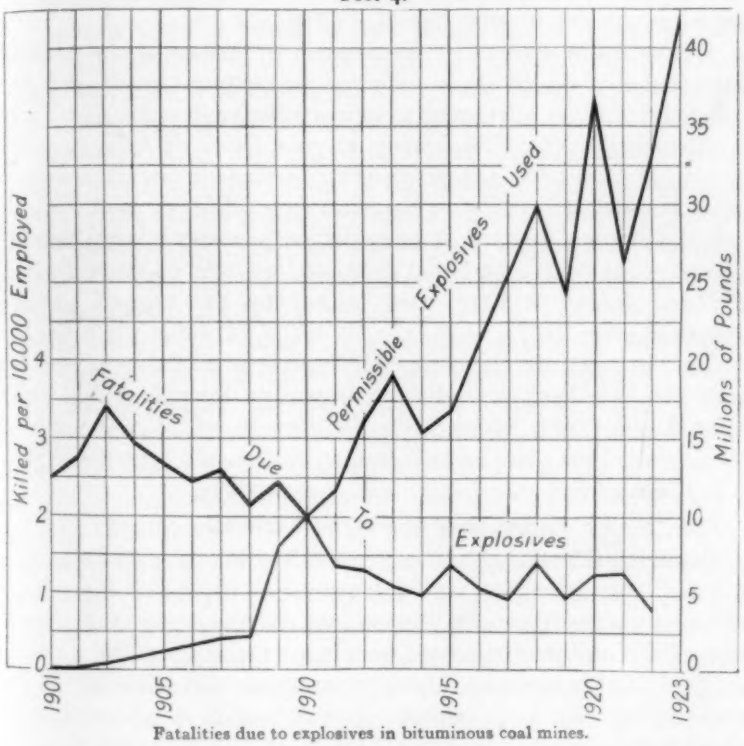
To illustrate, when ammonium nitrate, which will pass a sixty-mesh screen, is used in these explosives, the monobel has a velocity of detonation of about 3600 metres per second, but when the nitrate is granulated by a special process into rounded grains or globules instead of sharp-pointed particles or crystals such as are obtained by grinding the salt, an explosive of exceptionally low velocity of detonation is produced, as low as 1800 metres per second, so that the velocity can be varied between 1800 and 3600 metres per second.

I have here samples of ammonium nitrate prepared so as to vary the velocity of detonation of explosives in which it is used. (Fig. 3.)

It is a curious fact that no explosive of the gelatine type has ever been placed on the permissible list in this country until the present year, although this class has been in use abroad for many

years. Only last December it was felt that an explosive of this type would prove useful in moving rock in gaseous mines, where a stronger and denser explosive was desired, than the ammonia type. Owing to our previous studies and experience it was not a difficult matter to develop such a power depending upon the use of ammonium chloride in conjunction with sodium nitrate as a

FIG. 4.



Fatalities due to explosives in bituminous coal mines.

cooling agent. (U. S. Patent 887,027, 1907, to Bichel.) It is a 30 per cent. non-freezing gelatine and has proved to be useful not only in moving rock, but also coal, and especially in shooting from the solid where undercutting is not resorted to, and has been proven adaptable for the production of lump coal in spite of its relatively high velocity of detonation between 2330 and 4051 metres per second according to the diameter of the cartridge.

I have thought it might be of interest to present a chart showing the decrease in the number of fatalities due to the use of

explosives in coal mines in comparison with the rapid increase in the use of permissibles. This chart has been prepared from figures reported by the Bureau of Mines. It would seem that the flattening of the curve of fatalities for the years after 1915 is probably due to the fact that explosives other than permissibles are still used in bituminous coal mines, and also that the number of fatalities are not much more than occur in the ordinary handling of explosives in other mines. (Fig. 4.)

I have made inquiry of the Bureau of Mines, as to whether their statistics would show whether any explosions of gas and coal dust could be attributed to permissible explosives, and I beg to quote their reply: "Referring to your letter of July 31st, the Bureau of Mines has not published any statistics of mine explosions classified according to the kind of explosives used. However, the Bureau's record of mine disasters covers a large number of explosions of gas and coal dust, and to date no such disaster has been found to have been caused by the use of permissible explosives."

This is certainly a most gratifying piece of information for those who have been expending their energy along these important humanitarian lines, not only in the Bureau of Mines, but also among the coöperating manufacturers, and should spur the miners on to the extended use of this class of explosives.

SUBSTITUTES FOR NITROGLYCERINES.

Realizing that the annual increase in the use of high explosives in which nitroglycerine was the principal explosive ingredient, and since glycerine is a by-product of the soap and candle industry, it was felt that sooner or later there would be a world shortage of this material, and our attention was directed, at the inception of our laboratories, to the question of substitutes for nitroglycerine.

In fact, for several years prior to the world war in 1914 the world shortage seemed to be upon us, although I have sometimes thought that this was due to the accumulation of large stocks by the German Government in anticipation of war. There is no doubt that there would have been such a shortage had not some substitute been found and utilized during the last quarter century.

As early as 1885, through the efforts of R. S. Penniman and J. C. Schroeder, ammonium nitrate was used to some extent as a partial substitute for nitroglycerine in so-called straight and

gelatine dynamites to the extent of about ten pounds of nitrate of ammonia for seven pounds of nitroglycerine, but on account of its hydroscopic properties it was found necessary to protect it from atmospheric moisture by coating it with petrolatum by a process invented by Penniman in the same year.

This substitution gradually reduced the average percentage of nitroglycerine used in dynamite from 40 per cent. to 30 per cent.

Although earlier attempts had been made to utilize nitrated sugar in dynamite, Dr. A. M. Comey, of our Eastern Laboratory, discovered that if refined glucose or cane sugar were dissolved in glycerine the mixture could be readily nitrated under the refrigeration process, at that time in general use, but that a special process was necessary to purify the nitrated mixture, and after several years' work it was found possible to utilize a mixture of 80 per cent. glycerine and 20 per cent. sugar in all classes of explosives, and by this means 20 per cent. of the glycerine was substituted.

The use of nitro bodies in low-freezing explosives also reduced the consumption of glycerine and the high percentage of ammonium nitrate in the monobel class had a similar effect. Many attempts have been made to utilize potassium and sodium chlorate as well as picric acid in commercial explosives, but without any appreciable success in this country and only moderate success in Europe. Sodium perchlorate is used to a limited extent, it being much safer to handle and store than the chlorate, but its cost of production will prohibit its extended use.

Many attempts were made, about 1900 and later, to manufacture a stable nitrated starch and many samples which were claimed to be stable were secured which disappeared after storage through fire due to spontaneous combustion. This problem was attacked early in our work and was satisfactorily solved early in 1904 by the discovery that when ammonium oxalate is mixed with the explosive in very small proportions, say from .5 per cent. to 5 per cent., either wet or dry, a satisfactory stable nitrostarch could be produced (U. S. Patent 891,420 to F. B. Holmes), and it was afterward found that many other ammonium salts, both organic and inorganic, produced similar effects as well as such substances as oxamid and aniline oxalate, all of which have been covered by U. S. patents. Explosives containing this base have been manufactured and used ever since.

This explosive, however, has never been used in conjunction with nitroglycerine, and produces, when mixed with other ingredients, a dry powder which has limited application. Explosives of this class have an advantage in that they are non-headache producing.

The only explosive which has been found to be satisfactory for shooting oil wells is nitroglycerine, and several attempts have been made to find a substitute since no railway will transport liquid nitroglycerine, and consequently it has to be manufactured in small uneconomical plants located near enough to the oil fields to enable it to be transported by wagon or truck. Its advantages for shooting oil wells are its liquid state and consequent adaptability for filling the long, cylindrical cans used for lowering the explosive into the well and its high density of loading and sensitiveness, so that it can be exploded without failure by a small cap placed on a heavy " Go-devil " which can be dropped into the well, thus avoiding the use of long electric lead wires which would be necessary for a large electric detonator.

In 1909 it was found that blasting gelatine could be used for this purpose, and since then the use of the liquid has been abandoned in districts too far from existing nitroglycerine plants to transport the liquid safely in trucks, and in time may displace it altogether.

When nitrostarch was finally stabilized, it was thought that it might be used for shooting oil wells if it could be compressed into the proper sized cylinders and made waterproof. Compressed blocks were made of this material mixed with a small proportion of oil to protect it from the water, and then dipped in nitrobenzene which formed a protective coating of colloid on the blocks, but it was found to be practically impossible to detonate the blocks, this thin protective coating being intact, with dry nitrostarch, nitrocotton, or even dynamite as a primer, but that if the coating were removed to the slightest extent to expose the ungelatinized material it could be readily detonated.

A similar experience was met with in the old standard submarine mines, used by the U. S. Government. These were loaded with compressed wet guncotton blocks, and were supposed to be detonated by a primer of dry guncotton. The metallic container of the primer, or even a thin rubber bag container, prevented the propagation of the explosion to the wet blocks. I was

told by an army officer that even wire gauze was sufficient to prohibit detonation. During the Spanish War, dynamite was resorted to in submarine mines on account of the unreliability of the standard charge.

After a visit to Europe in 1908 when I saw two large plants in Germany for the manufacture of trinitrotoluene, I became convinced that this material would become of great importance in the future, and on my return immediately started work on a process for its manufacture, and, after much laboratory investigation, a small plant was built and operated successfully in the spring of 1910.

The product of this plant was used in low-freezing dynamites, as I have mentioned before. In 1910 I was in a position to bring this explosive to the attention of the Army and Navy and succeeded in interesting the Chief of the Coast Defense, and after some experimenting on material we were able to furnish, it was adopted for submarine mines by that department.

The first large plant for the manufacture of this important explosive was built to fill an order for 500,000 pounds, to be delivered in one year, for submarine mines; and thus this country was provided with knowledge and experience to meet the exigencies of world war in the production of this explosive.

Owing to the great demand for trinitrotoluene during the world war, every effort was made to either increase the supply of toluene or to find substitutes, and although the supply of the latter was greatly augmented by the efforts of the Government and others from coke and gas works, we first bent our efforts to its production by cracking coal and water-gas tar, and also by the Friedel and Craft reaction from benzene, and the reverse reaction from xylene and the higher homologues. Plants were built and operated both by cracking and by the action of aluminum chloride on xylene and the higher homologues.

It occurred to me, however, that we should be able to make trinitroxylene on a large scale and utilize it in connection with trinitrotoluene. Trinitroxylene is not suitable alone for shell and other bursting charges on account of the high melting point (182° C.) and consequent difficulty of loading, the melting point of trinitrotoluene being 80.6°, well below the boiling point of water. It was at first thought that a eutectic mixture could be

made of these substances which would melt low enough to be cast, but it was found that this was not the case as the xylene body was very slightly soluble in the toluene body. However, it was found that a mixture of 40 per cent. trinitroxylene and 60 per cent. trinitrotoluene could be brought into a sufficiently fluid state at temperatures below the boiling point of water to enable it to be readily cast into shells (U. S. Patent 1,309,588, July 8, 1919, to C. L. Reese) and form a compact filling without the attendant difficulties which were met with in loading that highly important mixture of ammonium nitrate and trinitrotoluene known as "Amatol," which was developed in England during the war.

The castings when cooled were completely amorphous, showing no segregation of the ingredients. They were free from air holes, had high and uniform density, were non-hygroscopic and showed no tendency to become oily or leaky when stored at high temperatures. This mixture showed many advantages over T.N.T.—in fact, almost an ideal explosive for filling shells.

Our first work on this explosive was done in 1913, but was abandoned on account of the press of other work, but in the summer of 1917, for the reasons which I have just enumerated, it was taken up again. The laboratory work and the development of the manufacturing process consumed more than a year and a half, and as a result a plant was constructed for the production of 30,000,000 pounds of T.N.X. to fill an order for the U. S. Navy. Two of the five units of the plant were completed and in satisfactory operation at the time of the armistice, with the other units nearing completion or in partial operation. (For more details see article by John Marshall, entitled "The Manufacture of Trinitroxylene for Use as a Substitute for T.N.T. in Bursting Charges for High Explosive Shells," *J. Ind. Eng. Chem.*, Vol. 12, No. 3, p. 248, March, 1920.)

To revert to the question of nitroglycerine substitutes, I have felt for many years that no substance could be found which would displace nitroglycerine unless it had some of its physical qualities as well as its explosive nature. In the first place, it is a liquid; it has considerable density and has an oily viscous nature; it dissolves nitrocellulose producing a colloid or gelatinous material; it is practically non-volatile; it can be made perfectly stable, though it can be readily detonated; and when mixed with absorb-

ents, it can be handled and transported under a reasonable amount of care.

Its liquid, dense, and oily nature makes it possible to produce explosives of high density when mixed with solid materials, the liquid filling in the space between the solid particles. These mixtures are plastic and can be readily packed in paper cartridges closed only with folds of paper; the paper cartridges can be slit or opened on the slides and the powder packed in the bore hole, securing high loading density. The advantages of this remarkable explosive could be further enumerated, to say nothing of cost of production. To secure a satisfactory substitute these qualities should be duplicated in a substance which should be without the physiological properties of stimulating the action of the heart and consequent production of severe headaches, and should cost little or no more than nitroglycerine.

Many attempts have been made to find such a material without success up to the present, but it might be of interest to mention some of those which have been proposed.

It is true that glycerine has been synthesized, though not economically. It has also been produced by fermentation in Germany, under the stress of the necessities of war, from beet sugar, but this raw material is too expensive for its normal commercial production. This is a problem on which we have been working for many years, starting, however, from a much cheaper source of sugar, namely, molasses. The use of this raw material introduced complications due to the impurities in the molasses, but a process has been developed to overcome these difficulties, and I feel that I can safely predict that after some chemical engineering difficulties, met with in large-scale production, have been overcome, this process will be put into practical operation.

With the exception of nitroglycerine, there are few liquid organic bodies which contain an excess of oxygen for their own combustion, although ethylene glycol dinitrate does contain the theoretical amount of oxygen to convert the carbon into carbon dioxide and the hydrogen into water. This substance should, therefore, come the nearest to being a substitute for nitroglycerine. It produces a stable dinitrate and can be readily synthesized from alcohol and has been used to a considerable extent in spite of the fact that it is more volatile than nitroglycerine.

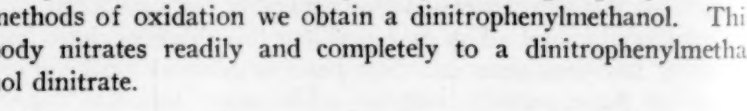
Butylene glycol dinitrate was also synthesized in our laboratories about 1911.

$$CH_2-CHOH-CH_2-CH_2-OH$$
$$CH_2-CH(NO_3)CH_2-CH_2-(NO_3)$$

It has an oxygen deficiency, though not as much as T.N.T. It could also be used as a substitute for nitroglycerine to some extent, but it is more difficult to nitrate except at very low temperatures without decomposition and therefore has never been utilized.

Propylene, trimethylene and many other aliphatic glycol dinitrates have been prepared but not used.

Much work has also been done on a class of bodies which may be termed nitro-nitrates. We named these bodies nitro-nitrates, because of the structure of the compounds. These compounds contain nitro groups substituted for the hydrogen in the benzene ring, and in this sense are true nitro-aromatic bodies, but they also contain nitrate groups attached as nitrate esters of the primary alcohol groups present in the compound. They may be formed by several methods; for example, we may start with xylene and by nitrating the benzene nucleus and transforming the two paraffin side chains into primary alcohol groups by suitable methods of oxidation we obtain a dinitrophenylmethanol. This body nitrates readily and completely to a dinitrophenylmethanol dinitrate.



$$C_6C_6-C_6H_4(CH_3)_2$$
$$C_6H_2(CH_3)_2(NO_3)_2$$
$$C_6H_2(CH_2NO_3)_2(NO_2)_2$$

Some of the nitro-nitrates [1] which we have prepared are well-crystallized solid bodies of a light canary yellow, and show about the same properties, so far as ease of detonation and strength are

[1] U. S. Patent 1,309,551, July 8, 1919, to C. M. Stine. U. S. Patent 1,311,926, Aug. 5, 1919, to C. M. Stine. U. S. Patent 1,370,067, March 1, 1921, to C. M. Stine.

concerned, as those which characterize tetryl, *i.e.*, the well-known trinitrophenylmethylnitramine, as well as tetra-nitro-analin.

Others of these nitro bodies are more or less viscous liquids at ordinary temperatures. These liquids, for the most part, are easily miscible in varying proportions with nitroglycerine, are somewhat less sensitive than nitroglycerine to shock and friction, and we would expect them to be somewhat less easily detonated by means of a blasting cap.

Some of these nitro-nitrates colloid nitrocellulose with ease; others only with difficulty after the application of heat and a volatile solvent. The chemical stability of these nitro-nitrates, when stored for considerable periods of time at elevated temperatures, varies with the structure of the molecule.

Another class of bodies has been prepared as substitutes for nitroglycerine with the idea of securing bodies of less potential. These bodies are the nitration products of esters of hydroxy aliphatic acid such as glycol or glycerine esters of lactic, tartaric acid, etc. As an example, glycerine dilactates can be readily nitrated with mixed acid to form a trinitro body of the following structural formula:

$$\begin{array}{l} CH_2-CO_2-CHOH-CH_3 \\ | \\ C-HOH \\ | \\ CH_2-CO_2-CHOH-CH_3 \end{array}$$

to

$$\begin{array}{l} CH_2-CO_2CHONO_2-CH_3 \\ | \\ CHNO_2 \\ | \\ CH_2-CO_2-CHONO_2-CH_3 \end{array}$$

This body is a viscous liquid having an oxygen deficiency of −67.8 per cent. as compared with an excess of 2.9 per cent. for nitroglycerine and a deficiency of −74 per cent. for trinitrotoluene. It is sufficiently insoluble in water to neutralize and stabilize, and colloids nitrocellulose.

A large number of similar bodies have been prepared for the purpose of securing one having the properties which were desired for a special purpose which I am not at liberty to discuss. As far as I know, this class of bodies has not been prepared before.

UTILIZATION OF EXCESS WAR MATERIALS.

At the close of the world war, there were in the hands of the U. S. Government approximately the following amounts of explosives:

330,900 lbs. fulminate of mercury
1,720,000 lbs. nitrostarch
60,500,000 lbs. ammonium nitrate
100,000,000 lbs. T.N.T.
6,500,000 lbs. ammonium picrate
20,000,000 to 25,000,000 lbs. picric acid
200,000,000 lbs. smokeless powder.

The question immediately arose as to what to do with this enormous amount of explosive material. It was even seriously proposed to dump the picric acid into the ocean and I believe this disposition was made of a small quantity. I was opposed to this wasteful destruction of valuable material, feeling that it could all eventually be utilized in one way or another. The fulminate of mercury, nitrostarch and ammonium nitrate have probably largely, if not entirely, been used in commercial explosives.

Much of the picric acid and T.N.T. has been used as high explosives by the Government in road building and distribution to farmers. The statistics as to the quantities thus used are not available, except for 1923 when 7,737,000 pounds of picric acid were distributed in this way. Forty-five per cent. of T.N.T. was mixed with 55 per cent. of sodium nitrate to take care of the oxygen deficiency of the T.N.T. packed into cartridges and distributed under the name of "Sodatol."

The question as to what to do with the smokeless powder was a more difficult one, for as such it could not be utilized as a high explosive, as even the cordite containing nitroglycerine could not be detonated by a commercial detonator in its existing condition. The smokeless powder was principally of the nitrocellulose type in granulations varying from the small rifle size to the large gun size. There was, however, a large quantity of cordite.

For the information of those not familiar with the distinction between these two kinds of powder, I might say that cordite is primarily a mixture of nitroglycerine and guncotton containing about 13 per cent. nitrogen, colloided with acetone, and the later forms contain a small percentage of petrolatum, whereas the pyro powders are made of nitrocellulose of a lower degree of nitration

(12.6 per cent. nitrogen), soluble in ether and alcohol mixtures and colloided with the same. It contains a small percentage of diphenylamine as a stabilizing agent, the alcohol and ether being dried out of the powder and recovered after its production.

The Government offered much of this powder for sale at very low prices, so that it became important to find methods for its utilization. It was known that finely divided pistol cordite could be detonated with a blasting cap, and a method of comminuting the relatively large grains had to be sought. Grinding with ordinary machinery seemed out of the question on account of the danger of fire, but it was found that it could be safely ground in an attrition mill with a stream of water flowing through the mill with the powder at all times, in spite of the fear of a number of powder experts that this method would not prove safe.

It has thus been possible to grind, not only the nitrocellulose powders, but also cordite, down to a fineness of 100 to 200 mesh without difficulty. Satisfactory high explosives have been made and used, of either kind of powder, or both, mixed with other ingredients. As examples, Dumorite No. 1 has the following formula:

20 per cent. pyro powder
48 per cent. cordite
31 per cent. nitrate of soda
1 per cent. chalk

Dumorite No. 2:

60 per cent. pyro powder
3 per cent. nitroglycerine
36 per cent. nitrate of soda
1 per cent. chalk.

It will be noted that a small amount of nitroglycerine is used in the latter formula for the purpose of rendering the explosive less dusty, bulky, and consequently less dangerous to manufacture and handle, and also for the purpose of increasing the sensitiveness to detonation, and the strength and velocity of detonation.

When nitroglycerine is mixed with an excess of nitrocellulose, it has a tendency to gelatinize and produce a sticky mass which hardens with age and eventually becomes extremely insensitive to detonation, but when the proportion of liquid is not above 10 per cent. in the explosive, and the time and temperature of mixing are

sufficient to allow gelatinization to come to completion during the time of mixing, and the moisture content of the ingredients is held between 0 per cent. and 2 per cent., an explosive entirely satisfactory from the standpoint of strength, velocity of detonation and freedom from dust is produced, and of more importance, it retains a soft granular structure indefinitely and can be completely detonated with a commercial blasting cap (U. S. Patent 1,420,364 to L. O. Bryan).

It may be of interest to note that recently a contract was awarded by the Government for one hundred million pounds of dynamite under the name of "Pyrotol," made on a formula similar to the Dumorite No. 2, using ground Government pyro powder and Government nitrate of soda, to be distributed for road building and farming purposes, such as stump blasting, tree planting and ditch digging for draining. This is of interest because, in spite of being a contract for high explosives to be used in peace time, it is the largest single contract which has ever been made for high explosives.

In concluding, I wish to say that I have only been able to summarize in a very general way some of the more important results of the work which has been done at our Eastern Laboratory, which confines itself primarily to research on subjects connected with the manufacture of high explosives. It has been impossible to go into scientific details, since the results of this and other work, which I have not mentioned, are covered by many reports, too voluminous to even read.

I have also been unable to touch upon many important developments in smokeless powder, or improvements in acid manufacture or solvent recovery. Our efforts have been to advance the art and to reduce the danger, not only in the manufacture, but also in the handling, transportation and use of a material intended to work by explosion, and thus reduce accidents to humanity to the minimum.

Note on a Search for the Missing Element No. 43. C. H. BOSANQUET and T. C. KEELEY. (*Phil. Mag.*, July, 1924.)—This element should resemble manganese. About a dozen manganese minerals were examined. They were made a part of the anti-cathode in an X-ray tube. The rays coming from them were reflected from a crystal of calcite upon a photographic plate. The results were, however, negative. G. F. S.

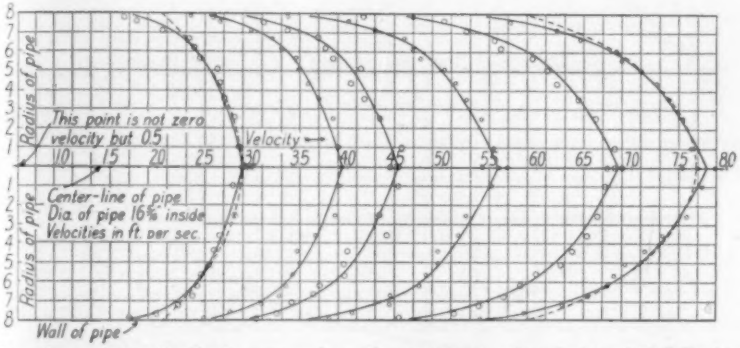
A NEW THEORY OF FLUID FLOW.*

BY

ANTHONY BRUCE COX.

IT IS well known that when a fluid, liquid or gaseous, flows through a long straight pipe of circular cross-section, then regardless of whether the flow is stream line (laminar, or non-sinuous) or turbulent (sinuous), the velocity of the elements of flow is greatest at or near the centre of the pipe and becomes less and less at greater and greater distances from the centre, until, as many authorities claim, near the wall of the pipe the velocity

FIG. 1.


Radius of pipe
This point is not zero velocity but 0.5
Velocity
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Center-line of pipe
Dia. of pipe 16⅝ inside
Velocities in ft. per sec.
Radius of pipe
Wall of pipe

Water flow velocity-distribution curves from *Transactions American Society of Civil Engineers* (Vol. 47, Plate 4, Fig. 1).

becomes zero. Many curves showing this variation of velocity across the diameter of a pipe have been obtained experimentally at various times by various investigators working mainly with the fluids air and water. The curves shown in Fig. 1 are for water and are taken from Plate 4 of Vol. 47 of the *Transactions of the American Society of Civil Engineers* for 1902. As just stated, many authorities believe that when a fluid " wets " the pipe, a thin film of unknown thickness clings to the wall of the pipe and does not move with the rest of the moving fluid.[1] The only curve known

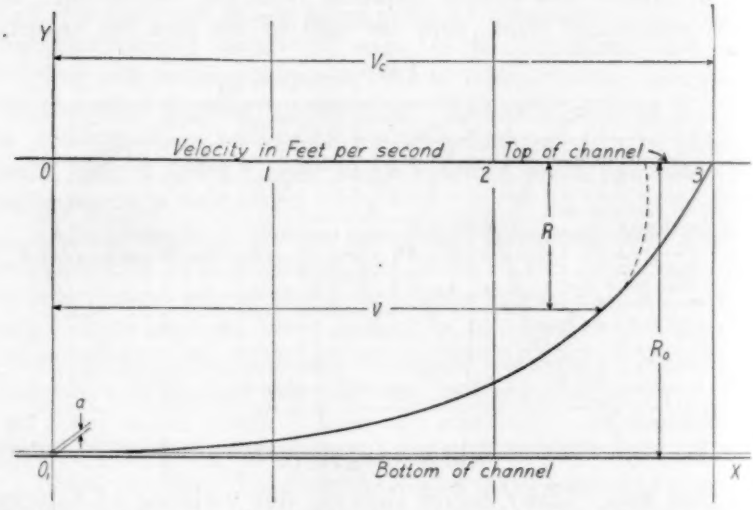
* Communicated by the Author.

[1] Ganot's " Physics," 18th Ed., 1910, p. 137, paragraph 147; also Edser's " Physics," p. 491; Daniell's " Physics," p. 316; Watson's " Physics," p. 188; Morrow, *Proc. Roy. Soc. London*, Vol. 76-A, 1905; Stanton, *Proc. Roy. Soc. London*, Vol. 85-A, 1911, and Vol. 97-A, 1920; Walker, Lewis and McAdams, " Principles of Chemical Engineering," p. 36.

to me which will represent the condition of the fluid across the entire diameter of the pipe and yet account for the existence of this stationary film, is the exponential curve (or logarithmic curve, depending on the form in which it is written; it will be referred to hereafter only as the logarithmic curve), whose equation is $y = ae^{bx}$ (1), a being the thickness of the stationary film, and b a constant multiplier of the velocity.

An examination of the various velocity-distribution curves accompanying this paper shows that whether the rate of flow is

FIG. 2.



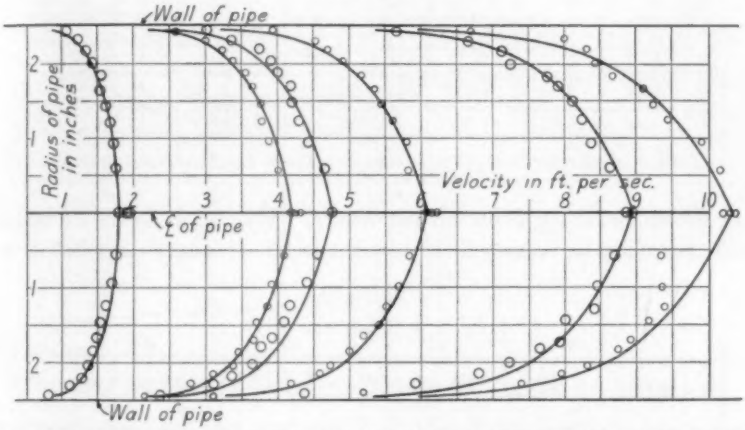
Fluid flow velocity-distribution diagram for derivation of formula for velocity-distribution curve.

above or below the critical, the elements of flow at different distances from the centre-line of the pipe have different forward velocities, and that hence these elements must be considered to "slide" or otherwise move relative to one another in this direction—this regardless of whether the elements of flow are made up of the same individual molecules of fluid during the entire length of the flow element being considered, or whether the individual molecules move (by diffusion, or otherwise) from one element of flow to another. Regardless of what the force may be called—whether simply fluid friction, viscosity, or coefficient of viscosity, there is a force by which the molecules of the various elements of flow are each enabled to affect the speed of the others,

this also regardless of whether the flow is stream line or turbulent. This phenomenon is the cause of the characteristic shape of the curve of velocity-distribution, and upon it a mathematical proof of the logarithmic form of the curve can be based.

Fig. 2 shows a curve of velocity-distribution for water flowing full in an open channel of rectangular cross-section. The channel is assumed to be so wide that the side walls do not exert any appreciable effect on the velocity-distribution at the vertical section shown in the figure. If the bottom O_1X of the channel were

FIG. 3.

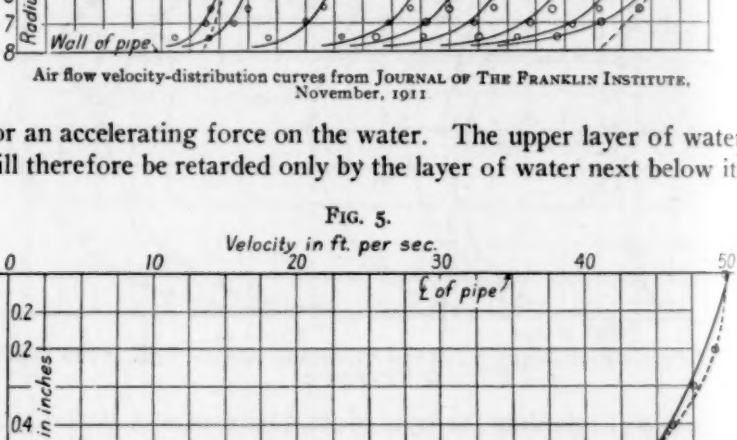


Water flow velocity-distribution curves from *Transactions American Society of Civil Engineers* (Vol. 57, Plate 25).

incapable of retarding the layer of fluid lying next to it, this layer would of course move as fast as the fluid in the body of the channel, and the velocity-distribution curve would be a straight line parallel with OY. But since the layer of fluid is held back by the bottom of the channel, this layer cannot move as fast (it probably does not move at all, except by diffusion) as the layers which are farther away from the bottom and which are therefore not so much affected by it. Due to the viscosity, or internal friction of the fluid, the layer of fluid next to the bottom of the channel exerts a retarding force on the layer of fluid next above it; this second layer retards the third layer, etc., etc., until the top layer is reached, which retards or accelerates only the air above it. If the air is stationary, or if it is moving in a direction opposite to the direction of flow of the water, the velocity-distribution curve

will be "hooked" backward, as is shown in dotted line in the figure. (See curves on p. 253 of Unwin's "Hydraulics.") For the sake of simplicity the wind will be assumed to be blowing in the same direction as that in which the water is flowing and with the same surface velocity V_e, so that it exerts neither a retarding

FIG. 4.



Air flow velocity-distribution curves from JOURNAL OF THE FRANKLIN INSTITUTE, November, 1911

nor an accelerating force on the water. The upper layer of water will therefore be retarded only by the layer of water next below it.

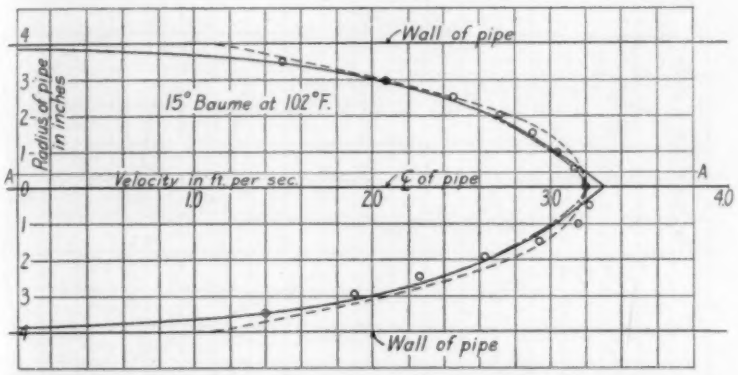
FIG. 5.

Air flow velocity curve from *Proceedings, Royal Society* (Vol. 85A, 1911).

Now the energy for retarding all the layers of fluid from the bottom to the top layers is furnished by the action of the bottom of the channel on the bottom layer of water. All the energy for retarding all the other layers of water has to be transmitted by

this bottom layer to the layer of fluid next above itself; this second layer has to transmit all the remaining energy for retarding the rest of the layers above itself, and so on until the next to the top layer is reached, which has to transmit only the energy that retards the top layer. In order to transmit this relatively greater amount of energy, the lower layers of the fluid are displaced relatively to one another to a greater and greater extent as the bottom layer is approached. Under simple, perfect conditions of flow, the relative difference in velocity between layers would be inversely

Fig. 6.



Heavy oil flow velocity-distribution curve from Fig. 13, "The California Oil Pipe Line."

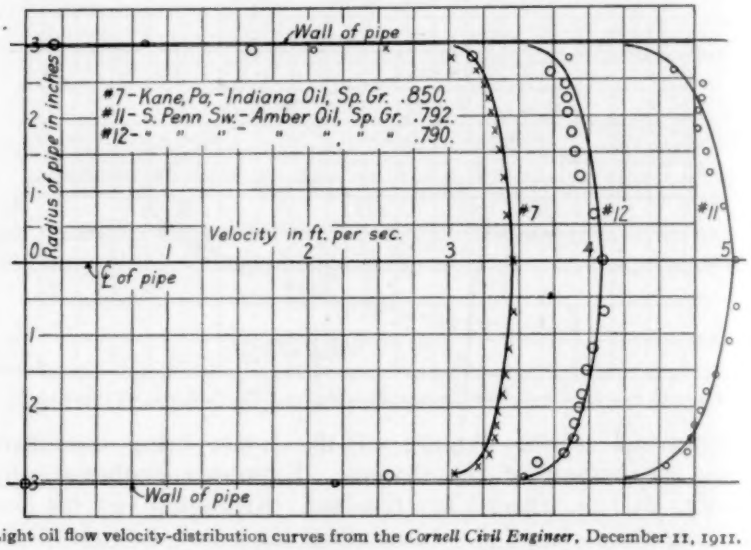
proportional to the distance of the layers being considered from the bottom of the channel. Expressed mathematically, $dy/dx = by$ (2), where b is a constant. Arranging (2) for integration, $dy/y = bdx$ (3). Integrating, $\log y + c = bx$ (4). Solving for c, $c = bx - \log y$ (5). When $x = 0$, $c = -\log a$ (6). Substituting this value in (4), $\log y - \log a = bx$ (7). Combining terms: $\log y/a = bx$ (8). Expressing exponentially, $y/a = e^{bx}$ (9). Clearing fractions, $y = ae^{bx}$ (1). From Fig. 2, $y = R_o - R$ (10), and $x = V$ (11). Substituting these values in (1), $R_o - R = ae^{bV}$ (12).

In the flow of water in long straight pipes of circular cross-section, the reasoning is the same and the figure is the same (Fig. 9) except that the line forming the top of the channel in Fig. 2 becomes the centre-line of the pipe in Fig. 9. In the pipe, therefore, the layer of water immediately above the centre-line of the pipe (corresponding to the wind in the case of the channel)

flows at the same velocity as the layer immediately below the centre-line, and hence neither layer exerts any disturbing effect—either of acceleration or of deceleration—on the other. This accounts for the sharp "nose" seen in some of the more carefully taken velocity-distribution curves accompanying this paper. The reasoning and the proof are applicable to the other classes of fluids also.

In order to show how closely this curve corresponds to actual flow conditions, the points from various velocity-distribution

FIG. 7.

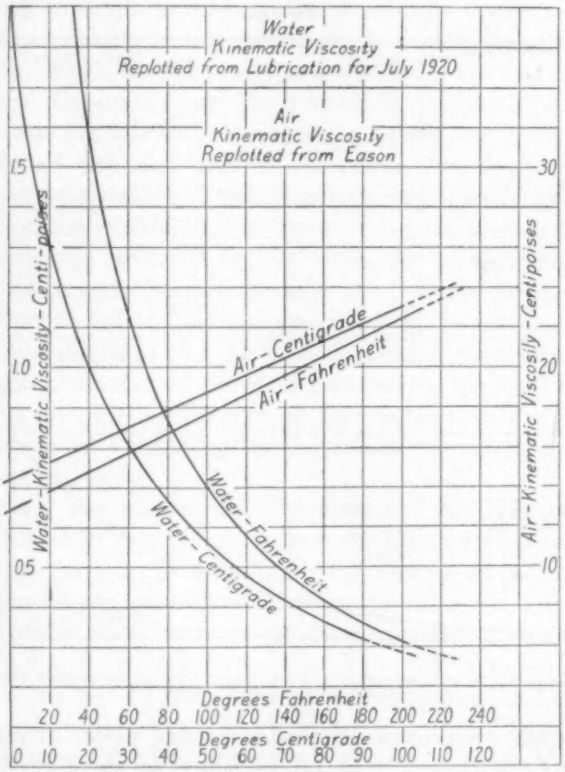

Wall of pipe
#7 - Kane, Pa, - Indiana Oil, Sp. Gr. .850.
#11 - S. Penn Sw. - Amber Oil, Sp. Gr. .792.
#12 - " " " " " " " .790.
Radius of pipe in inches
Velocity in ft. per sec.
#7
#12
#11
℄ of pipe
Wall of pipe

Light oil flow velocity-distribution curves from the *Cornell Civil Engineer*, December 11, 1911.

curves obtained by various experimenters at various times have been plotted in Fig. 1, and in Figs. 3 to 7 inclusive, and instead of drawing in the curves which these experimenters drew in, a logarithmic curve with the constants that best average the points has been drawn in for each case. Although the curves shown cover experiments with such varied fluids as air, water, and light and heavy oils, it would be very difficult to draw in a symmetrical curve of any sort that would fit the experimental points better than these theoretical curves do. It might be argued that in some cases, particularly that of heavy oil flow in Fig. 6, the junction of the curves at the centre-line has been made too sharp, but it is easily seen from this figure that the point of maximum velocity of this

curve does not lie on the centre-line of the pipe. The maximum velocity may have occurred in a plane at right angles to the plane of the curve shown, or more probably in a plane inclined at an angle of approximately 45° to the section shown. In either case the plotted points would represent a section of the "dome," or surface of revolution outlined by the logarithmic curve shown. In order

Fig. 8.

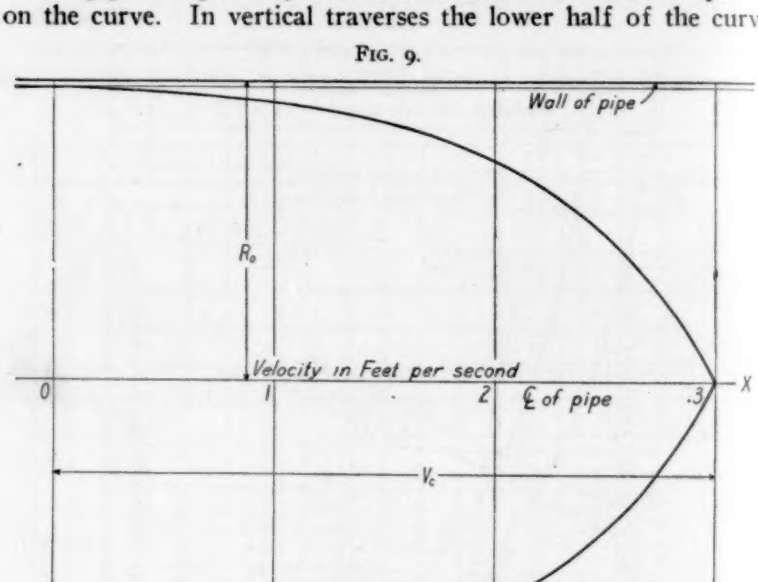


Temperature-viscosity curves for air and for water.

to show this effect, a section $A - A$ has been taken 0.4″ from the centre-line of the pipe, and the curve of the resulting sectional outline drawn in in dot and dash line in the figure. Since the chances are rather small that flow in ordinary commercial piping will be so smooth and undisturbed that the maximum velocity will often occur at the centre-line of the pipe, it is probable that in most cases of velocity measurement a distribution curve with a

round point will be obtained, just as a section of a sharp-pointed cone is round nosed. If the point of the dome, representing the maximum velocity, whips back and forth and around the centre-line of the pipe at the section where the velocities are being measured, the value obtained for the velocity of flow at the centre-line of the pipe will probably be the most unreliable of all the points on the curve. In vertical traverses the lower half of the curve

FIG. 9.



Fluid flow velocity-distribution diagram for derivation of formula for average velocity of flow, and formula for friction loss.

would appear to be more affected by stones, pieces of metal, sand or dirt, etc., too heavy to be carried along by the current, settling along the bottom of the pipe. In this connection it may be well to state that some fluid flow authorities have found that the Pitot tube itself noticeably affects the velocity-distribution curve so that one-half the curve appears to move at a slower rate of speed than the other. By using a tube that passed through both walls of the pipe, they have demonstrated to their own satisfaction that this was the case. Other authorities (Estep) state that with a mixed fluid there is a tendency for the component fluids to separate and

flow in fixed strata relative to one another. In a mixture of fluids of different densities and viscosities, such as air, this phenomenon would undoubtedly affect the regularity of the velocity distribution curve. (Figs. 4 and 5.)

Fig. 9 has been drawn for the purpose of making clear the development of formulæ for average velocity of flow and for friction loss. It is a diagrammatic representation of the velocity distribution of a fluid flowing with a centre velocity of 3 feet per second through a long, smooth, straight pipe of circular cross-section. The values of the constants a and b have been taken as 0.00521 (1/16") and 1.387, respectively. The natural origin of this logarithmic curve is a fixed point O_1 on the wall of the pipe and does not change its position for different velocities of flow. It is assumed that that part of the curve extending to the left of the Y-axis represents virtual velocities only, that is, the stressed condition of the stationary film due to the attraction of the molecules of the pipe material for the molecules of the film and the opposing frictional effort of the molecules of the moving fluid to carry it along. When the attraction between the molecules of the pipe material and those of the fluid is greater than the attraction between the molecules of the fluid themselves, the fluid is said to "wet" the pipe and a thin film of fluid adheres to the pipe wall. Further evidence for taking the logarithmic curve as the correct one will appear later.

In giving the mathematical derivations, the relations of a and b will first be worked out. For the sake of convenience the origin in the formula $y = ae^{bx}$ (1) is transferred to the centre-line of the pipe and the symbols made to conform to the flow problem by substituting $R_o - R = y$, and $V = x$, or $R_o - R = ae^{bV}$ (12). When $V = V_c$, $R = 0$, and $R_o = ae^{bV_c}$ (13). From equation (12), $e^{bV} = (R_o - R) \div a$ (14). Taking the logarithm of both sides, $bV = \log (R_o - R) - \log a$ (15), and $\log a = \log (R_o - R) - bV$ (16). In order to determine the value of b from a velocity-distribution curve previously obtained by experiment, read two values of velocity, as V_1 and V_2 at radii R_1 and R_2, respectively, and substitute in (16), thus obtaining $\log a = \log (R_o - R_1) - bV_1$, and $\log a = \log (R_o - R_2) - bV_2$. Equating these two values of $\log a$ and solving for b, $b = \dfrac{\log \left[\dfrac{R_o - R_1}{R_o - R_2}\right]}{V_1 - V_2}$ (17). If V_1 be taken as

V_c, and V_2 as any other velocity V at radius R, (17) becomes:

$$b = \left[\frac{\log\left(\frac{R_o}{R_o - R}\right)}{V_c - V}\right], \tag{18}$$

or in common logarithms,

$$b = \frac{2.3026}{V_c - V}\log_{10}\left[\frac{R_o}{R_o - R}\right]. \tag{19}$$

If V is selected as V_m, the velocity of flow at a point half-way between the centre-line and the wall of the pipe, (19) reduces to $b = \frac{0.6933}{V_c - V_m}$ (20). Formula (20) can be expressed in the form $b = \frac{0.6933}{V_c} \div \left[1 - (V_m/V_c)\right]$ (21). For convenience in writing let

$$\frac{1}{1 - (V_m/V_c)} = m, \tag{22}$$

and (21) may then be written as

$$b = \frac{0.6933m}{V_c}. \tag{23}$$

These particular values of velocities may not be the best for the actual determination of b, but are chosen for the purpose of making comparison with other formulæ easy.

In (16), when $V = V_c$, $R = 0$, and $\log a = \log R_o - bV_c$ (24). Substituting the value of b from (23), $\log a = \log R_o - 0.6933m$ (25). It will be seen from a comparison of (23) and (25) that b depends for its value on the maximum velocity of flow V_c and upon m, and that a depends for its value on the radius of the pipe R_o and upon m, and from (22) it is seen that m is dependent for its value only upon the ratio V_m/V_c.

For the purpose of comparing one velocity-distribution curve with any other curve taken in a different size of pipe, it is convenient to find the value of V (represented by V_1) for the value $y = 1$. This is the theoretical velocity the curve would have at the centre-line of a 24-inch pipe if the radius of the actual pipe were increased (or decreased, as the case might be) to unity (one foot). The derivation of the formula for V_1 is as follows: $R_o - R = ae^{bV}$ (12). When $y = 1$, $R_o - R = 1$, $V = V_1$, and (12) becomes: $1 = ae^{bV_1}$ (26). Expressing logarithmically, $\log 1 -$

$\log a = bV_1$ (27). Solving for V_1 ($\log 1 = 0$), $V_1 = \frac{-1}{b} \log a$ (28). Substituting (24) in (28), $V_1 = \frac{-1}{b} \log R_0 + V_0$ (29).

Values of V_c, b, $\log_{10} a$, V_a (V_m/V_c), f and V_1 are given in Tables I, II, and III for the distribution curves shown in this paper. The tables show that the value of the ratio V_m/V_c is different for different sizes of pipes and possibly also for different velocities of flow. The value of the ratio for a given fluid is also probably dependent on the known or easily determinable characteristics of the fluid such as density and viscosity. Since these vary very greatly in most fluids with variation in temperature, and thereby affect the values of the constants a and b which appear in the flow formulæ derived later on in this paper, it will be seen that the recording of the temperature is an important feature of flow experiments.[2] Fig. 8 has been plotted in order to show the practical importance of temperature in water flow tests. It will be noted from the curves that the viscosity at 32° F.—an ordinary temperature for water in the winter time—is twice the value of the viscosity at 70°—say in mid-summer—and over six times the value of the viscosity at ordinary boiler feed temperatures—say at 210°.

The values of $\log a$ in Tables I, II, and III, as well as the method of calculating them, should be of interest to those interested in the thickness of lubricating oil films in connection with lubrication problems. Table IV gives a general idea of the

TABLE I.

Water.

V_c	b	$\text{Log}_{10} a$	V_a	V_m/V_c		V_1	d	Fig. No.
10.34	0.90	−4.724	8.67	.923	.848	12.08	5″	3
9.00	1.10	−4.978	7.64	.929	.848	10.43	5″	3
6.10	1.50	−4.654	5.10	.922	.836	7.15	5″	3
4.78	1.70	−4.211	3.90	.915	.816	5.71	5″	3
4.20	2.00	−4.328	3.45	.918	.822	4.99	5″	3
1.80	4.00	−3.808	1.43	.903	.792	2.19	5″	3
7.80	1.35	−4.749	6.69	.937	.858	8.09	16″	1
6.87	1.40	−4.347	5.80	.930	.844	7.16	16″	1
5.60	1.60	−4.052	4.66	.922	.832	5.83	16″	1
4.54	2.00	−4.113	3.79	.925	.835	4.74	16″	1
3.94	2.30	−4.100	3.29	.926	.835	4.11	16″	1
2.90	2.80	−3.703	2.36	.914	.814	3.05	16″	1

[2] Butcher, *Engineering News*, Vol. 76, 8-7-16.

TABLE II.

Air.

V_c	b	$\text{Log}_{10}a$	V_a	V_m/V_c	f	V_1	d	Fig. No.
57.2	.24	−6.136	50.95	.950	.8910	58.90	16″	4
54.2	.26	−6.293	48.43	.951	.8935	55.70	16″	4
50.2	.30	−6.716	45.20	.954	.9005	51.63	16″	4
45.6	.33	−6.710	41.05	.954	.9000	46.83	16″	4
42.2	.35	−6.590	37.91	.953	.8985	43.33	16″	4
39.2	.38	−6.648	35.25	.954	.8995	40.28	16″	4
32.6	.47	−6.828	29.41	.955	.9020	33.43	16″	4
26.2	.58	−6.774	23.61	.956	.9013	26.88	16″	4
24.0	.70	−7.466	21.86	.958	.9110	24.53	16″	4
50.2	.12	−3.696	37.70	.885	.7510	70.90	2″	5

TABLE III.

Oils.

V_c	b	$\text{Log}_{10}a$	V_a	V_m/V_c	f	V_1	d	Fig. No.
3.30	1.1	−2.05	2.94	.809	.891	4.30	8″	6
5.04	5.0	−11.54	4.74	.968	.941	5.32	6″	7
4.10	7.4	−13.77	3.90	.977	.951	4.29	6″	7
3.46	9.4	−14.72	3.30	.977	.954	3.61	6″	7

TABLE IV.

Fuid.	$\text{Log}_{10}a$	a in Feet.	a in Inches.
Water	−4.4	1/25120	1/2093
Air	−6.7	$1/5.012 \times 10^6$	$1/4.177 \times 10^5$
Light Oil	−14.72	$1/5.25 \times 10^{14}$	$1/4.374 \times 10^{13}$
Heavy Oil	−2.054	1/113.25	1/9.44

thickness of the fluid films of different fluids at ordinary temperatures. The experiments of Stanton [3] on boundary conditions of a fluid indicate that the calculated value of the film thickness for air is probably not far wrong.

Unfortunately, the published tests referred to in this paper do not cover a sufficient range of definitely known densities and viscosities to permit of the discovery of the relation of these characteristics to the constants a and b, or to the ratio V_m/V_c, and the facilities for making such tests are not at present available to me. However, with suitable apparatus, the law by which these constants depend on the physical characteristics of fluids should not be difficult to determine. In most of the published data, the density, viscosity, and temperature are either only partially stated, or altogether omitted and left to be inferred. If necessary,

[3] *Proc. Roy. Soc. London*, Vol. 97-A, 1920.

in making these tests, suitable baffles or screens (see Estep) may be placed near the entrance end of the pipe to assist in the even distribution of the flow across the diameter of the pipe. The Pitot tube may be mounted on a guide which extends through the opposite wall of the pipe to insure that the tube shall at all times project in a direction parallel to the axis of the pipe (see Morrow). A micrometer adjustment may be combined with the tube and its guide, because in taking readings near the wall of the pipe, a very slight error in reading R results in a relatively large error in the V reading (see Morrow). The temperature, both of the fluid itself at the section where the velocity is being measured, and of the surrounding medium, should be regularly recorded throughout the test—if possible, the fluid should not radiate heat to, or absorb heat from, the medium surrounding the pipe. After the law for "ideal" flow has been fully determined, the effect of the various variables occurring in commercial flow may probably be accounted for and allowance made for them in the formulæ.

For the calculation of logarithmic curves for comparison with velocity-distribution curves experimentally obtained, it has been found best to find b by formula (19) or (20), and eliminate a from the velocity formula as follows: From (15), $V = \frac{1}{b}[\log (R_o - R) - \log a]$. Substituting the value of $\log a$ from (24):

$$V = \frac{1}{b} \log \frac{R_o - R}{R_o} + V_c \quad (30), \text{ or } V = \frac{2.3026}{b} \log_{10} \frac{R_o - R}{R_o} + V_c \quad (31).$$

In order to make the checking of experimentally obtained velocity-distribution curves still easier, a table of value of $\log_e \frac{R_o - R}{R_o}$ has been worked up.

TABLE V.

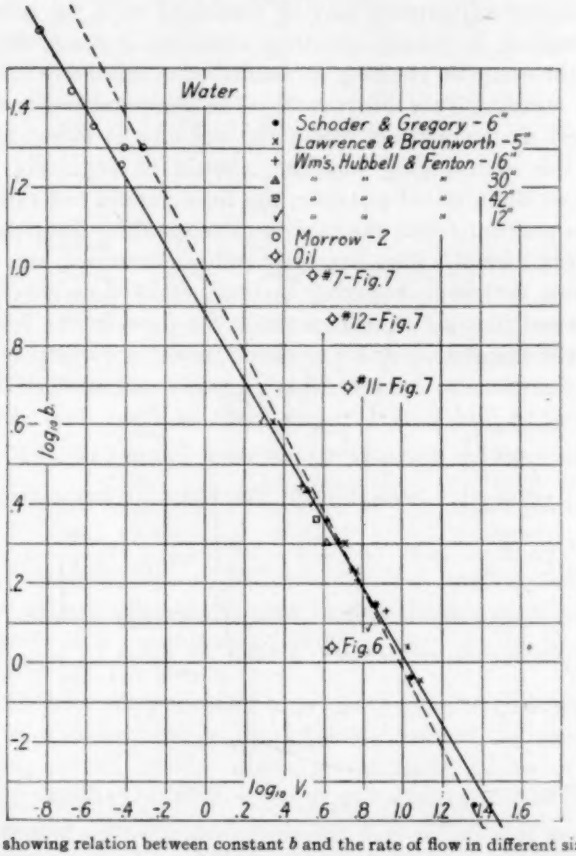
R/R_o	$\text{Log}_e \frac{R_o - R}{R_o}$	R/R_o	$\text{Log}_e \frac{R_o - R}{R_o}$
0	0	.6	−.9166
.1	−.10526	.7	−1.2040
.2	−.22324	.8	−1.6100
.3	−.35640	.9	−2.3026
.4	−.5110	.95	−2.9950
.5	−.6935	.98	−3.9140

In order to find the points of a theoretical velocity-distribution curve for comparison with an actual one, it is only necessary to

assume a value for b, divide the values of $\log_e \frac{R_o - R}{R_o}$ in the table by b and add the result algebraically to V_c.

In order to compare the curves of this paper which were obtained with various sizes of pipes and various rates of flow,

FIG. 10.

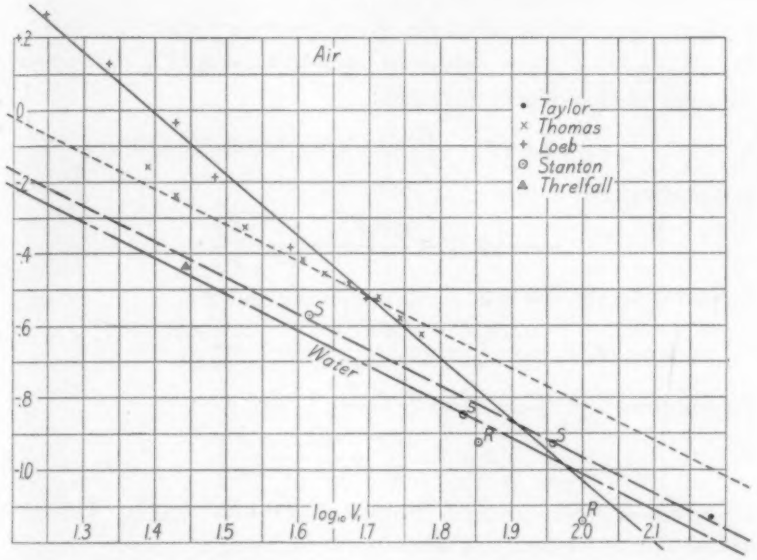


Water curve showing relation between constant b and the rate of flow in different sizes of pipes.

V_1, the theoretical velocity each theoretical curve would have at a distance of unity from the pipe wall ($R_o = 12''$) has been calculated and tabulated in Tables I, II, and III. From Fig. 10 it is seen that for the water flow curves, when $\log_{10} b$ is plotted against $\log_{10} V_1$, the result is an approximately straight line. The solid line seems to average the points best, but I believe that inasmuch

as the dotted line fits the points from Professor Schoder's high-velocity water flow curves, which are considered more reliable than Morrow's low-velocity curves, it is probably the more nearly correct line. This dotted line has an exponent of unity for V_1 in the formula $b = m_o/V_1^{M_o}$ (32), and m_o is approximately 9.55. For air, the points $\log_{10} b$ *vs.* $\log_{10} V_1$ do not lie so accurately on a straight line, though it appears possible that they may do so under identical test conditions. In Fig. 11, the solid line represents the

FIG. 11.



Air curve showing relation between constant b and the rate of flow in different sizes of pipes.

straight line for air flow which best averages all the plotted points. The long dash line represents the line determined by Stanton in two experiments with 3-inch (approximately) pipe having a smooth surface. The exponent of V_1 in formula (32) is unity for this line. The other points obtained by Stanton are marked with an R or S to indicate rough or smooth pipe, respectively. Evidently the roughness of the pipe affects the value of the constant m_o—and hence b—and from a consideration of the relative position of the air, water, and oil flow points in Figs. 10 and 11, it appears that density and viscosity affect it also. But since, as will be shown later, b appears in the friction loss formula, this is

the only result that could properly have been expected. The short dash line in Fig. 11 represents a reasonable equation for Thomas' experiments in which the exponent of V_1 is equal to unity. The line representing the equation for water has been drawn in Fig. 11 for comparison with those for air.

The formula for average velocity of flow will now be determined. Referring to Fig. 9, the volume v of the solid of revolution formed by revolving (12) about the axis of the pipe, divided by the area of the cross-section of the pipe, will give the value of the average velocity of flow V_a. The formula for the volume of a solid of revolution about the X-axis is $v = \pi \int y^2 dx$. From (12), $R = R_o - ae^{bV}$ (33). Squaring: $R^2 = [R_o^2 - 2aR_o e^{bV} + a^2 e^{2bV}]$. Substituting in the volume formula:

$$v = \pi \int R^2 dV = \pi \int (R_o^2 - 2aR_o e^{bV} + a^2 e^{2bV})\, dV.$$

Integrating:

$$v = \pi \left[R_o^2 V - \frac{2aR_o e^{bV}}{b} + \frac{a^2 e^{2bV}}{2b} \right]_0^{V_c}.$$

Substituting the limits:

$$v = \pi \left[R_o^2 V_c - \frac{2aR_o e^{bV_c}}{b} + \frac{a^2 e^{2bV_c}}{2b} \right] - \pi \left[0 - \frac{2aR_o}{b} + \frac{a^2}{2b} \right].$$

Substituting the value of ae^{bV_c} from (13),

$$v = \pi \left[R_o^2 V_c - \frac{3R_o^2}{2b} + \frac{2aR_o}{b} - \frac{a^2}{2b} \right]. \tag{34}$$

The cross-sectional area of the pipe is $A = \pi R_o^2$ (35). The value of the average velocity is therefore:

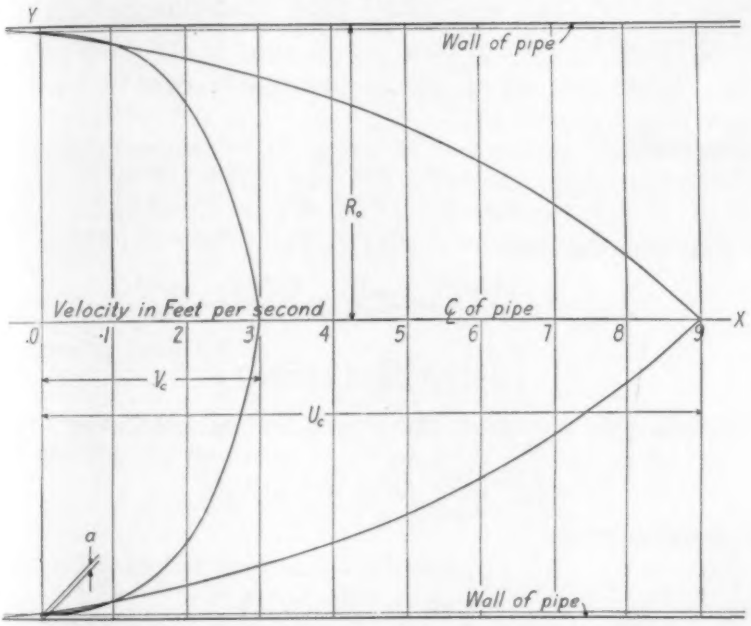
$$V_a = \frac{v}{A} = \left[V_c - \frac{3}{2b} + \frac{2a}{bR_o} - \frac{a^2}{2bR_o^2} \right]. \tag{36}$$

But since, as has already been seen (Table IV), a is very small, the last two terms of (36) may be neglected (except for very small pipes or for very viscous liquids), and $V_a = V_c - 1.5/b$ (37), and $V_c = V_a - 1.5/b$ (38). If the ratio of the average velocity to the maximum velocity at the centre of the pipe be represented by f, $V_a = fV_c$ (39). Substituting in (37) and solving for f, $f = [1 - 1.5/bV_c]$ (40). Substituting (20) in (40), $f = 1 - 2.164\,[1 - (V_m/V_c)]$ (41). Substituting (22) $f = 1 - 2.164m$ (42). Recalling the lack of temperature record in most experiments, both the temperature of the fluid within the pipe and of the

medium surrounding the pipe often being lacking, equation (42) very largely explains the widely varying values for f obtained by different experimenters with the same fluid but at different times.

There are numerous friction loss formulæ for air and for water, of the form $H_l = KV_a^c l/R_o$ (43), or $H_l = KQ^e l/R_o^3$ (44), where the value of c for different rates of flow approaches 2 as a maximum. It would seem much more logical to use the effective or root mean square (r.m.s.) velocity V_e rather than the average

FIG. 12.



Fluid flow velocity-distribution diagram for derivation of r.m.s. value of velocity.

velocity V_a. In order to prevent useless duplication of this investigation by others to whom the same thought may occur, the derivation of V_e will be given.

Solving (15) for V, $V = \frac{1}{b} \log \frac{(R_o - R)}{a}$ (45). In Fig. 12 the value of the Y-coördinates of the V-curve are given by (45). The value of any Y-coördinate of the U-curve is given by $U = V^2 = \frac{1}{b^2} \log^2 \frac{(R_o - R)}{a}$ (46). In order to get the r.m.s. value of

the V-curve, the solid of revolution generated by revolving the U-curve about the axis of the pipe must be found and divided by the area of the pipe cross-section, and the square root of the result taken. Or in symbols:

$$V_e^2 = \frac{\pi}{\pi R_o^2} \int R^2 dU. \tag{47}$$

Squaring (33),

$$R^2 = [R_o^2 - 2R_o a e^{bV} + a^2 e^{2bV}]. \tag{48}$$

Since $U = V^2$ (46), $dU = 2V dV$ (49). Substituting (48) and (49) in (47):

$$V_e^2 = \frac{1}{R_o^2} \int (R_o^2 - 2R_o a e^{bV} + a^2 e^{2bV})\, 2V dV$$

Integrating:

$$V_e^2 = \left[\frac{2V^2}{2} - \frac{4a}{R_o}\left(\frac{Ve^{bV}}{b} - \frac{e^{bV}}{b^2}\right) + \frac{2a^2}{R_o^2}\left(\frac{Ve^{2bV}}{2b} - \frac{e^{2bV}}{4b^2}\right)\right]_0^{V_c}.$$

Substituting the limits:

$$V_e^2 = \left[V_c^2 - \frac{4V_c a e^{bV_c}}{bR_o} + \frac{4ae^{bV_c}}{b^2 R_o^2} + \frac{V_c a^2 e^{2bV_c}}{bR_o^2} - \frac{a^2 e^{2bV_c}}{2b^2 R_o^2}\right] - \left[o - o + \frac{4a}{b^2 R_o} + o - \frac{a^2}{2b^2 R_o^2}\right]$$

Neglecting the a terms of this expression and substituting (13):

$$V_e^2 = \left[V_c^2 - \frac{4V_c}{b} + \frac{4}{b^2} + \frac{V_c}{b} - \frac{1}{2b^2}\right].$$

Combining terms,

$$V_e^2 = \left[V_c^2 - \frac{3V_c}{b} + \frac{3.5}{b^2}\right] \tag{50}$$ and $$V_e = \sqrt{V_c^2 - \frac{3V_c}{b} + \frac{3.5}{b^2}} \tag{51}.$$

Substituting (38) and expanding,

$$V_e = \sqrt{V_a^2 + \frac{3V_a}{b} + \frac{2.25}{b^2} - \frac{3V_a}{b} - \frac{4.5}{b^2} + \frac{3.5}{b^2}} = \sqrt{V_a^2 + \frac{1.25}{b^2}}. \tag{52}$$

In the case of air and water—particularly air—the second term of (52) is practically negligible for all ordinary velocities, so that V_e is, for all practical purposes, the same as V_a. This fact might be considered to account for the success of formulæ of the type given in (43). Otherwise there seems to be no basis in reason for the almost universal use of the average velocity in modern flow formulæ.

A more exact formula for friction loss is derived as follows: In Fig. 9, consider any cylinder of fluid of radius R and length l. The surface of this cylinder is given by the formula $S_l = 2\pi Rl$ (53). It is known from experiment and from approximate formulæ of the type of (43) that the coefficient of internal friction of fluids varies about as the square of the relative velocities of the two surfaces being considered, or in symbols, $\mu = k(dV)^2$ (54). Since some authorities believe that fluid friction between two layers of fluid moving at different relative velocities is due to the collision of the molecules of either layer of fluid diffusing over into the other layer and being collided with by the molecules of that layer, I have taken the exponent in (54) as exactly equal to two.[4] The retarding force acting on the cylinder of fluid being considered is $dF_l = \mu S_l l$ (55). This force acting through the length l of the cylinder gives the foot-pounds friction loss at radius R, or $dE_l = \mu S_l l^2$ (56). Substituting (53) and (54) in (56), $dE_l = 2\pi l^2 Rk(dV)^2$ (57). Substituting (33) in (57), $dE_l = 2\pi l^2 k(R_o - ae^{bV})\ (dV)^2$ (58). Integrating once:

$$E_l = 2\pi l^2 k \int R_o V dV - 2\pi l^2 ka \int \frac{e^{bV}}{b}\, dV.$$

Integrating again:

$$E_l = \left[\frac{2\pi l^2 k R_o V^2}{2} - \frac{2\pi l^2 k a e^{bV}}{b^2}\right]_0^{V_c}.$$

Substituting the limits:

$$E_l = 2\pi l^2 k\left[\left(\frac{R_o V_c^2}{2} - \frac{ae^{bV_c}}{b^2}\right) - \left(0 - \frac{a}{b^2}\right)\right]. \qquad (59)$$

Neglecting the last term, and substituting (13):

$$E_l = \pi l^2 k R_o\,(V_c^2 - 2/b^2). \qquad (60)$$

But the foot-pounds friction loss is also equal to the weight of fluid contained in the length of pipe l multiplied by the friction head loss, or in symbols: $E_l = W_l H_l = w\pi l R_o^2 H_l$ (61). Equating (60) and (61): $\pi l^2 k R_o(V_c^2 - 2/b^2) = w\pi l R_o^2 H$ (62). Solving for H_l,

$$H_l = lk\frac{(V_c^2 - 2/b^2)}{wR_o}. \qquad (63$$

Substituting (38) in (63): $H_l = lk\dfrac{(V_a^2 - 3V_a/b + 0.25/b^2)}{wR_o}$ (64). The

[4] Ganot's "Physics," p. 180, paragraph 194.

constant k for a given fluid flowing (at a known temperature) in a given kind of pipe is found by experiment and equation (65) derived from (64). Solving (64) for k:

$$k = \frac{wR_o H_l}{(V_a^2 + 3V_a/b + 0.25/b^2)}. \tag{65}$$

For air and other gases, it is more convenient to get rid of H_l and express the friction loss in terms of pressure. $P_l = wH_l/144$ (66), and $p_l = wH_l/9$ (67). Substituting (66) in (63),

$$P_l = lk \frac{(V_c^2 - 2/b^2)}{144R_o}, \tag{68}$$

and substituting (67) in (63),

$$p_l = lk \frac{(V_c^2 - 2/b^2)}{9R_o}. \tag{69}$$

There are few direct data available for checking these formulæ. However, Williams, Hubbell, and Fenkell state that for the 16-inch pipe tested by them, the velocity-distribution curves for which are shown in Fig. 1, the friction head loss per thousand feet of pipe can be approximately calculated by the formula $H_{1000} = 0.2114V_a^{1.86}$ (70). If then the formula for friction head loss (64), derived on the basis of the logarithmic flow theory, is correct, the values of k calculated for the various rates of flow in the 16-inch pipe by using the value of H_{1000}, found by (70), in formula (64) or (65) should all be the same within the limits of experimental error. These values of k have been calculated and tabulated in Table VI.

TABLE VI.

V_c	b	V_a	$0.2114V_a^{1.86}$	k_{1000}
7.80	1.35	6.69	7.255	5.075
6.87	1.40	5.80	5.550	5.007
5.60	1.60	4.66	3.702	5.045
4.54	2.00	3.79	2.522	5.230
3.94	2.30	3.29	1.9375	5.330
2.90	2.80	2.36	1.044	5.340

For the lower rates of flow the values of k seem to be larger than those for the higher rates of flow. But since it is well known that in formulæ of the type of (70) the exponent of V_a decreases with decreasing velocity, this apparent increase in the value of k may be accounted for in this way. It should be noted that the

lowest value of k given is not quite 2 per cent. less than the average value of k, and the highest value given is only about 3.2 per cent. greater than the average—results which are entirely within the limits of experimental error. An additional correction will be mentioned in this same connection in the following discussion of air flow.

No direct friction loss data were available for any of the air flow velocity-distribution curves shown in the figures accompanying this paper. However, by using the Sturtevant formula for air flow friction loss, $p_{1000} = \frac{l_{1000} V_a^2}{25000 d}$ (71), values of friction loss were calculated, which were then used in formula (69) to calculate k for the different rates of air flow in the 16-inch pipe, velocity-distribution curves for which are shown in Fig. 4. These calculated values for k are given in Table VII below. It will be noted from this table that the values of k for air flow also show a slight tendency to become larger with decreasing rates of flow. Whatever the complete explanation—whether due to decrease in the value of the V_a exponent, or whether due to inherent inaccuracies in Pitot tube measurements, or to both, Professor Thomas found that with decreasing rates of flow his measurements of velocity by Pitot tube deviated more and more from his measurements by the electrical method.

TABLE VII.

V_c	b	V_a	p_{1000}	k_{1000}
57.2	.24	50.95	6.484	.012025
54.2	.26	48.43	5.863	.012120
50.2	.30	45.20	5.107	.012280
45.6	.33	41.05	4.211	.012275
42.2	.35	37.91	3.593	.012220
39.2	.38	35.25	3.104	.012230
32.6	.47	29.41	2.160	.012290
26.2	.58	23.61	1.394	.012280
24.0	.70	21.86	1.193	.012520

The fact that formulæ of the type of (64) and (69) check friction loss data for water and air, respectively, is additional evidence of the correctness of the theory outlined in this paper. The method should be applicable to the flow of any fluid—steam, oil, gas, etc.—with the possible exception of fluids like mercury, which are supposed not to "wet" the pipe. However, since the

thickness a of the stationary film does not appear in the friction loss formula, the theory may hold for this class of fluids also.

In conclusion, it might be well to suggest some of the possible uses of the foregoing theory of flow and the formulæ developed. First, it makes possible the development of fluid flow formulæ which give promise that with the proper constants, they will probably be universally applicable to the flow of all kinds of fluids—air in ventilating ducts, water in water supply systems at any temperature, oil in oil pipe-lines, gas in gas-mains, steam in power plant piping, etc. This should result in simpler formulæ, make their application more general as well as more accurate, and should lead to a general understanding of the way in which a fluid actually flows. Second, it opens up a way for the complete practical solution of the centrifugal pump problem which furnished the impetus for this paper. Third, it furnishes a method of investigating the action of pumps, fans, propellers, water-wheels, steam-turbines, etc., in general, and should later be useful in their design. Fourth, it will result in a more accurate method of calibrating Pitot tubes, especially for certain velocities of flow. Fifth, it furnishes a tool for the investigation of the resistance to bodies moving through fluids—ships through water, automobiles and airplanes through air—and may later be of use in the calculation of the proper shape of the parts of these bodies in order that they may offer the least resistance to such movement. Sixth, it furnishes a tool for the investigation of fluid films in heat transmission problems, and oil films in lubrication problems. The method of calculating their thickness from easily made measurements should be particularly valuable. Seventh, similar methods may prove useful in the study of such physical phenomena as capillarity, molecular attraction in fluids, and in the investigation of other so-called "fluids."

The evidence in favor of the logarithmic curve as the form of velocity-distribution curves across the diameter of long straight pipes of circular cross-section will now be summed up. (1) The most important fact of all is that the logarithmic curve fits the points of velocity-distribution curves obtained by careful experiment, regardless of whether the velocities used are above or below the critical, and also regardless of whether the fluid used is a gas, or a light or a heavy liquid. (2) The mathematical proof of the log form of the velocity-distribution curve given at the begin-

ning of this paper is based on such simple and direct reasoning as to be difficult to challenge. (3) Practically all authorities state that a thin film of the fluid clings to the wall of the pipe and does not move with the rest of the moving fluid. No other curve but the log curve accounts for the existence of this film. (4) In the most carefully taken velocity-distribution curves, the two halves of the curve meet at the centre-line of the pipe at a distinct angle to each other, as is required by the mathematical proof. Round-nosed curves such as the parabola, ellipse, and catenary can therefore not accurately fit the points of experimentally obtained velocity-distribution curves. In less carefully taken curves, the velocity-distribution obtained is a section of the sharp-pointed dome or surface of the log-curve surface of revolution. In some of the figures of this paper parabolas have been drawn in in dotted lines for comparison with the logarithmic velocity-distribution curves. (5) The log curve has a natural origin which does not change or fluctuate with every change or fluctuation in the rate of flow. (6) The log curve permits of the derivation of fluid flow formulæ which appear to be generally applicable to all sorts of fluids, and which give results in reasonable accord with the facts.

ACKNOWLEDGMENTS.

Acknowledgment of obligation and thanks are due Mr. R. M. Hardgrove of the Bailey Meter Company, Cleveland, Ohio, for definite data on the distortion of the velocity-distribution curve by the Pitot tube.

Acknowledgment of obligation and thanks are also due to Prof. E. S. Schoder, Director of Experimental Hydraulics at Cornell University, for furnishing the original tabulated data for replotting the flow curves of Lawrence and Braunworth in Fig. 3, and for furnishing similar data for the oil flow curves in Fig. 7. Thanks are also due to Messrs. Lawrence and Braunworth for permission to use these data.

Acknowledgment and thanks are also due to the firm of Sanderson and Porter, New York, for the loan of published data not obtainable elsewhere.

Appreciation of the excellent service rendered by the employees of the Technology Department of the Carnegie Library of Pittsburgh should also be publicly acknowledged.

MEANING OF SYMBOLS.

l = length of pipe in feet.
R_o = radius of inside of pipe in feet.
R = any radius in feet.
d = diameter of inside of pipe in inches.
w = weight of a cubic foot of fluid in pounds.
W_l = weight of fluid in length of pipe l.
V_c = maximum velocity of flow at centre of pipe in feet per second.
V_a = average velocity of flow in feet per second.
V_1 = velocity of theoretical curve at $y = 1$.
V = velocity at any radius R in feet per second.
V_m = velocity at radius $R = R_o/2$.
v = volume in cubic feet.
v_l = volume of l feet of pipe in cubic feet.
μ = coefficient of internal friction of fluid.
k = constant in friction loss formulæ.
a = constant in logarithmic formula (thickness of stationary fluid film).
b = constant of logarithmic formula.
m = $[1 \div (1 - V_m/V_c)]$.
m_o = constant of formula connecting b and V_1.
M_o = exponent of V_1 in formula connecting b and V_1.
c = exponent in friction loss formula of the old type.
f = ratio of V_a to V_c.
U = V^2.
E_l = friction loss in l feet of pipe in foot-pounds.
F_l = retarding force acting on fluid in l feet of pipe in foot-pounds.
S_l = surface of cylinder l feet long and of radius R in square feet.
H_l = friction head loss in l feet of pipe in feet.
P_l = pressure drop in l feet of pipe in pounds per square inch.
p_l = pressure drop in l feet of pipe in ounces per square inch.
Q = quantity of flow in cubic feet per second.

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The foregoing list of references has been divided into four parts, the first part for water, the second for air, the third part for oil, and the fourth part general references. Some of the references overlap, so that the division cannot be strictly made.

Note.—All calculations in this paper were made with a 20-inch slide rule. All logarithms are to the base e (2.7183) unless noted as being to the base 10.

Film Protection as a Factor in Corrosion.—The question of the corrosion of the metals used in industrial systems has always been of great importance and has received a great deal of attention in the last few years with the result that some of the former views have been shown to be erroneous. In the study of the subject by F. N. SPELLER, of the National Tube Company, the corrosion of iron in closed water systems was studied. In large closed systems the combination of the mechanical de-aerator and a de-activator for removing oxygen serves well. In the smaller ones it is thought that the corrosion can be restrained by the use of compounds forming films upon the surface

of the metal. Experiments seem to show that the use of sodium silicate might be satisfactory even on a large scale in cold water supplies. With some domestic waters lime may be used to advantage, but must be carefully controlled. There seems to be no doubt that such films are of material use, but any system of treatment requiring the addition of such materials involves practical difficulties in controlling the rate of addition. Speller found, however, that the silicate treatment need not be continuous but may be omitted entirely for a few days at a time after a substantial film has been formed. It is not adapted to a hot water system. (*Proceedings of the American Electrochemical Society*, October, 1924.) H. L.

The Preparation of Pure Alloys.—R. F. MEHL, Juniata College, Pennsylvania, presented a paper on this subject at the meeting of the American Electrochemical Society in Detroit in October, 1924. In it he discussed the accuracy of metallographic data with particular reference to the effect of impurities upon electrical measurements. He referred to the various methods by which contamination has heretofore been avoided. A new method of making magnesia crucibles of high strength and density applicable up to 1200° C. was devised. He also described a combined furnace and casting apparatus by which pure alloys may be obtained in a form suitable for electrical measurement. His investigations so far have concerned preliminary measurements of the temperature coefficient of resistance and of the thermo-electromotive force upon certain compositions containing aluminum and magnesium. H. L.

ERRATA.

HEAVISIDE'S OPERATORS IN ENGINEERING AND PHYSICS.

BY

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Page 696, the last equation should read:

$$\therefore i = E\sqrt{\frac{C}{R}}\,\varepsilon^{-nx}\,p^{\frac{1}{2}}\,1 = E\sqrt{\frac{C}{\pi Rt}}\,\varepsilon^{-\frac{RC}{4t}x^2}$$

Page 699, equation (*a*) and that immediately preceding should read:

$$\frac{d^m}{dt^m}\,\frac{t^n}{\lfloor n}=\frac{t^{n-m}}{\lfloor n-m}$$

$$p^m\,\frac{t^n}{\lfloor n}=\frac{t^{n-m}}{\lfloor n-m} \qquad (a)$$

THE APPLICATION OF POSITIVE RAY ANALYSIS TO IONIZATION PROBLEMS.*

BY

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INTRODUCTION.

ALMOST simultaneously with the appearance of Bohr's first paper on atomic structure, Franck and Hertz, developing an idea of Lenard's, inaugurated a series of experiments which were to prove of great importance to theories of atomic constitution. They undertook to study the effect of collisions between slow electrons and gaseous molecules as a function of the speed of the electrons and the nature of the gas. Other investigators, notably Horton and Davies in England, McLennan in Canada, and Compton, Foote and Mohler in this country, took up the work and soon its direct relation to Bohr's ideas became apparent. It would be an interesting study to trace the mutual reactions of the two lines of investigation through the past decade, the experimental and the theoretical, each helping to solve the other's problems, yet at the same time propounding new ones. Such a discussion, however, is beyond the scope of this paper, which is less concerned with the triumphs of these experimental methods than with their limitations. These can be made evident by a brief presentation of the principles involved and the results obtained up to 1921.

All these experiments on "ionization potentials" are done in gases at low pressures in tubes in which are sources of low speed electrons, usually filaments, and various grids and plates insulated from each other. The general idea is to increase the speeds of the electrons (whose initial speed is small) by applying a known electric field and to study the variation in the currents between electrodes as a function of the applied field. The methods are discussed and references to original papers given in Foote and

* Communicated by Dr. K. T. Compton, Professor of Physics, Princeton University.

Mohler's recent book.[1] Here, too, the results are given in detail, but for our purpose they may be adequately presented in a few sentences. In monatomic gases and metallic vapors it was found that there were critical speeds which the electron had to attain before it could transfer energy to the atom; that the lowest critical energy corresponded to changing of the outer electron of the atom from its normal orbit to the next possible stationary state and that successive critical energies corresponded to raising the electron to stationary states of higher potential energy until finally it was removed entirely, ionization taking place. These conclusions resulted from the comparison of the experimental observations with spectroscopic data as interpreted by Bohr's theory. Unfortunately, lack of spectroscopic evidence makes this procedure difficult for most substances, and even for the higher degrees of ionization of the metallic vapors. Thus, in the case of polyatomic molecules the complicating factor of dissociation and the meagreness of spectroscopic evidence makes the interpretation of experimental results very uncertain.

The difficulty lies in the limitation of the experimental methods. They detect the occurrence of ionization without giving any evidence as to the nature of the ion produced. Sometimes it is possible by indirect means to distinguish between single and double ionization or between molecular and atomic effects, but clearly it is desirable to get a direct method of analyzing the products of an ionization tube.

The mere word "analyze" at once suggests another type of experimental work, positive ray analysis, originated by J. J. Thomson and so brilliantly developed by Aston and Dempster. Here is a method for determining the ratio of the mass to the charge of an ion, and if it could be combined with the ionizing potential experiments discussed above, it should give the direct evidence desired as to the products of ionization. The difficulties of effecting such a combination are serious, but they have not proved insuperable. Their nature and how they have been overcome will be discussed in the following paragraphs, together with the results obtained by the methods developed and their bearings on ionization problems.

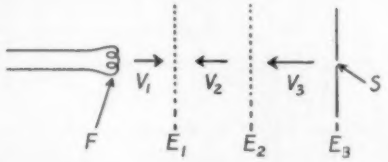
[1] "The Origin of Spectra," 1922, Chap. III.

EXPERIMENTAL METHODS.

The chief difficulty to be overcome becomes apparent when the schematic diagram in Fig. 1 is considered.[2]

This represents an arrangement of a filament and three electrodes such as was used in all the writer's experiments. Electrons are accelerated by the field V_1 toward E_1. In the neighborhood of E_1 they produce ions and are prevented from reaching E_2 by V_2.

FIG. 1.



It is the nature of these ions which is to be investigated. They are accelerated by the fields V_2 and V_3, and some pass through the slit S. After passing S and a second similar slit, the beam of ions so defined is bent by a magnetic field on to a third slit behind which is an insulated plate connected to an electrometer. The magnetic field necessary to bend the ions to the third slit depends on V_2 and V_3 and on the m/e of the ion. However, unless the pressure is so small that the mean free path of the ions is comparable with the distance from E_1 to the third slit, they will either never get through at all or they may lose or gain electrons by collision on the way and so make it impossible to decide what are the primary products of the impact between electrons of speed V_1 and the gas molecules.

On the other hand, there must be enough collisions of electrons and gas molecules between E_1 and E_2 to produce a measurable number of ions. Even with fairly low pressures this may be attained by having the electron density very high. Still it is clearly desirable to have a fair density of gas molecules between E_1 and E_2 and yet practically zero density everywhere else.

When first considering the problem, the writer saw no way of achieving these density variations with substances gaseous at ordinary temperatures, but in the case of the metallic vapors a possibility suggested itself. If a unidirectional stream of vapor

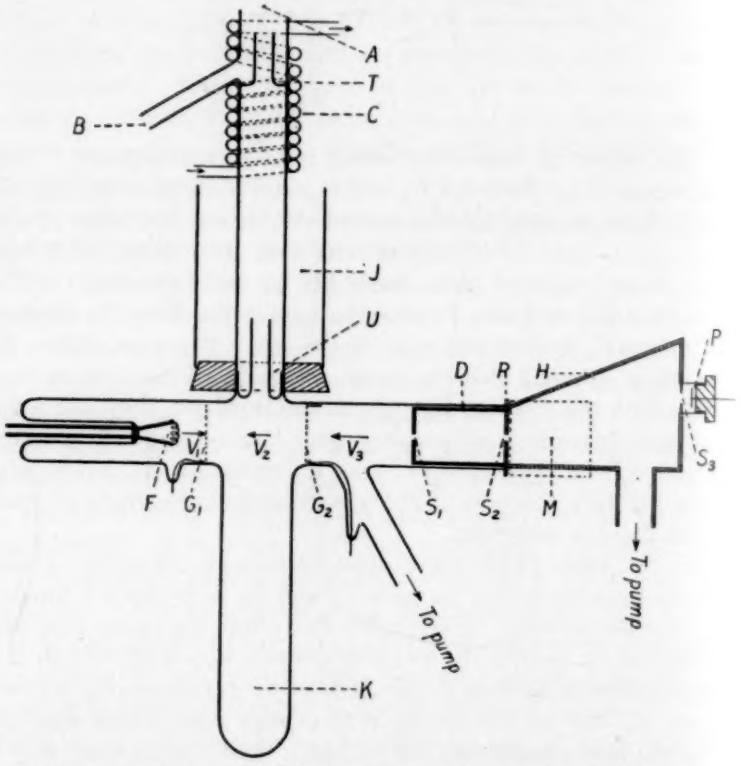
[2] The writer is indebted to the Council of the Royal Society for permission to reproduce the diagrams in this paper.

such as is used in a diffusion pump could be driven across the tube between E_1 and E_2, and then condensed by liquid air, there would be a much larger concentration between E_1 and E_2 than elsewhere in the ionization tube or positive ray box. The successful embodiment of this idea in an apparatus used for mercury vapor will now be described.

EXPERIMENTS ON MERCURY VAPOR.

Mercury was chosen as the most favorable substance to study first, chiefly because it lent itself so well to the production of

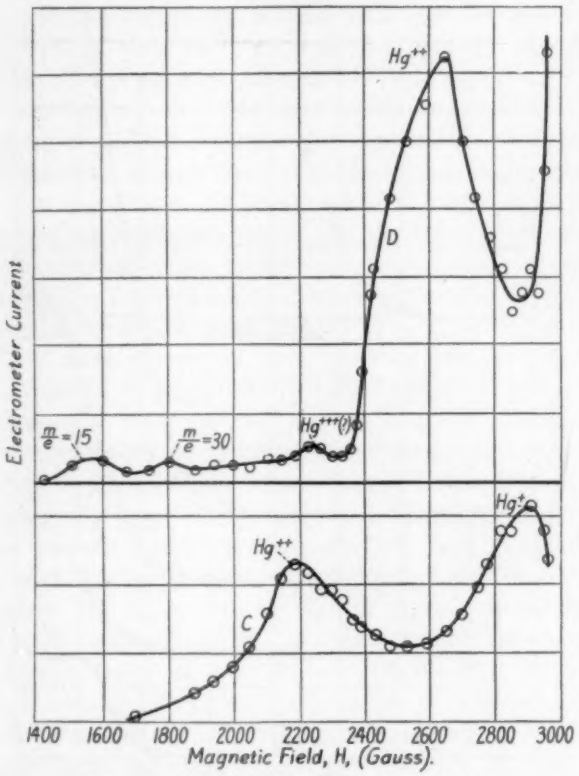
FIG. 2.



a unidirectional stream and also because its first ionizing potential was so well known that it would serve as a check on the method and a reference point. It was hoped that it would be possible to determine its second ionizing potential and perhaps even higher ones.

The apparatus used is shown in Fig. 2. It has been described in detail elsewhere [3] and only a few points will be recalled here. The arrangement of grids and slits corresponds exactly with that already described in the discussion of Fig. 1. Mercury vapor from a hot reservoir is made into a unidirectional stream by the

FIG. 3.



Curve *C*. $V_1 = -V_1 = 300$ volts. $V_3 = 300$ volts.
Curve *D*. $V_1 = -V_1 = 175$ volts. $V_3 = 610$ volts.

cooling jackets C and J, passes across between the grids G_1 and G_2 and is condensed in K by liquid air.

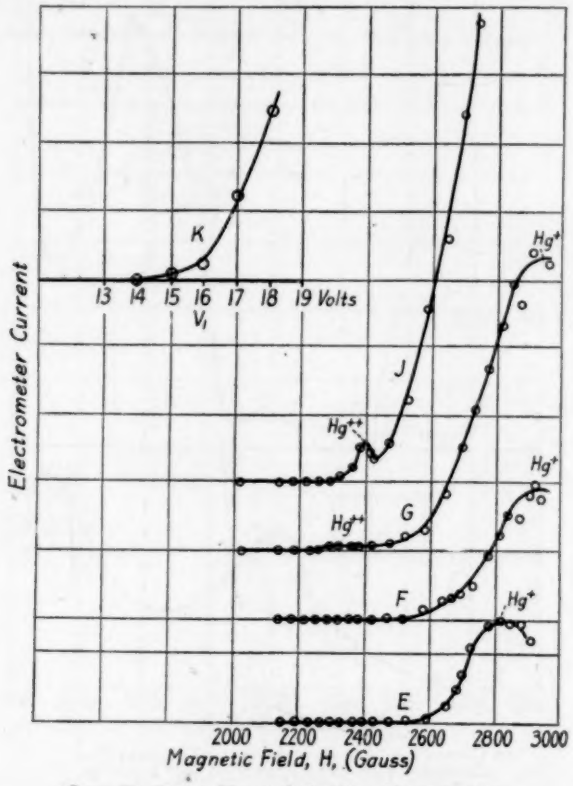
If this arrangement achieves the varying density conditions required and if V_1 is set at well above the ionizing potential, the current to P observed as a function of V_3 or of the magnetic field between the pole pieces M should show a strong maximum

[3] *Proc. Roy. Soc.*, **102**, 283–293, 1922.

corresponding to the value of m/e for Hg^+ and perhaps other maxima assignable to Hg^{++}, etc.

The procedure throughout the work on mercury was to keep all the electrical fields constant and observe the rate of charging of a Compton electrometer connected to P as the current through the magnet was varied. The magnetic field was read from a cali-

FIG. 4.



Curve E. $V_1 = -V_2 = 13$ (17) volts. $V_3 = 450$ volts.
Curve F. $V_1 = -V_2 = 16$ (20) volts. $V_3 = 490$ volts.
Curve G. $V_1 = -V_2 = 20$ (25) volts. $V_3 = 490$ volts.
Curve J. $V_1 = -V_2 = 25$ (30) volts. $V_3 = 480$ volts.
Curve K. $H = 2820$. $V_3 = 460$. Correction curve for E.
Values of V_1 given are corrected. Uncorrected values in parentheses.

bration curve previously obtained with a fluxmeter and coil. Two curves obtained by this procedure are shown in Fig. 3. On account of the different values of $V_2 + V_3$ used, the peaks do not occur at the same values of the magnetic field, H. In both cases

V_1 is so far above the ionizing potential that the Hg^{++} maximum is quite strong. The Hg^{+++} in curve D is doubtful as it was not reproducible. The small maxima at $m/e = 15$ and $m/e = 30$ are attributed to a trace of air. They will be mentioned again in connection with later experiments.

But such curves as these are only the first step towards our goal. The object of the experiment is to determine the critical energies for the formation of the multiply charged ions. At what value of V_1 does the Hg^{++} peak first appear? To determine this, series of runs must be taken at different values of V_1. Such a series is shown in Fig. 4. In order to obtain the effective voltage from the observed, the difference between the observed disappearance voltage for Hg^{+} and 10.4 volts, the known ionizing potential, is used as a correction. In the caption of Fig. 4 both corrected and uncorrected values are given and the curve K illustrates the method at arriving at the correction. For further discussion of this point and a detailed consideration of results, reference must again be made to the original paper.

Here it must suffice to state that the critical potential for double ionization of mercury was found to be 19 ± 2 volts. This value agrees with what evidence there is on the enhanced spectrum if it be supposed that the doubly charged ions result from impacts of electrons with atoms which are already singly ionized.

Before going on to the development of the method for gases, it should be mentioned that Kondratjeff and Semenoff [4] have recently used exactly the method described above for studying the ionization of the vapor of $HgCl_2$ and HgI_2. Their paper is a "preliminary communication" but their results show Cl^- and I^- present as products of ionization. Their data, however, are insufficient to throw light on the question of whether or not the critical energies correspond to those calculated by thermochemical equations. Certain aspects of this important question will be discussed in connection with the results of the experiments on gases which will now be presented.

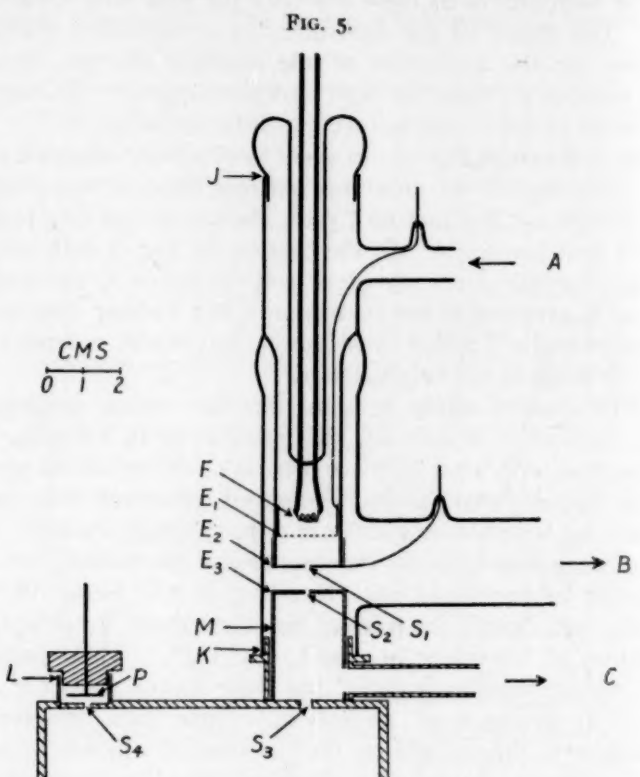
METHOD FOR GASES.

The small maxima in curve D (Fig. 3), apparently due to air, suggested that the application of this mode of attack to gases might not be so difficult as was at first anticipated. By a small

[4] *Zs. f. Physik*, **22**, 1–8, 1924.

modification of the apparatus used for mercury, it was found possible to get fairly sharp maxima for nitrogen, but the results of several months' work were inconclusive though suggestive. An entirely new apparatus, therefore, was designed and set up. It is shown in Fig. 5 and described in detail in a previous paper.[5]

FIG. 5.



It will be seen that the arrangement of electrodes is still the same as in Fig. 1, except that E_2 is now a plate with a single slit instead of a gauze. This change, of course, had to do with the new method used to get varying gas density. The gas to be

[5] *Proc. Roy. Soc.*, **104**, 121–134, 1923.

studied leaks in slowly at A and is pumped out by one Langmuir pump operating through B and a second through C and D. In this way it is possible to have a fairly high density of gas in the neighborhood of E_1, where the ions are formed, a lower density between E_2 and E_3 and still lower beyond E_3 in the positive ray box.

The positive ray analysis was very much improved by using a larger magnet and bending the rays in a semi-circle to get a focussing effect. The stray field from this powerful magnet caused much trouble and led to an important change in procedure. Whereas previously in a run all the electric fields had been held constant and the electrometer current observed as a function of the magnetic field, from this time on the latter was kept constant and V_3 varied.

We will now consider in some detail what type of curve might be expected. If it be assumed that the ions are formed at E_1 and suffer no collisions between formation and detection at P, then the electrometer currents plotted as ordinates against $\frac{1}{V_2 + V_3}$ as abscissas should give maxima corresponding to the m/e's of the ions produced at E_1. This is obvious from the equations for the effects of electric and magnetic fields on an ion

$$H\rho = m/e \times v \quad \text{and} \quad eV = 1/2\, mv^2$$

which combine to give $m/e = \frac{H^2\rho^2}{2V}$ where ρ is the radius of curvature; v, the velocity; H, the magnetic field, assumed uniform, and V, the potential drop through which the ion has fallen before entering the magnetic field. But in the light of some recent experiments at comparatively high pressures, it is important to consider the situation when the assumption made above is not strictly true; that is, when the ion is not formed exactly at E_1 or else collides somewhere along its path.

First, as to the place of formation, any ions formed on the filament side of E_1 are drawn back toward the filament and need not be considered. Also the electrons will lose their ability to ionize as soon as they have been retarded by such a fraction x of V_2 as is given by

$$xV_2 = V_1 - W$$

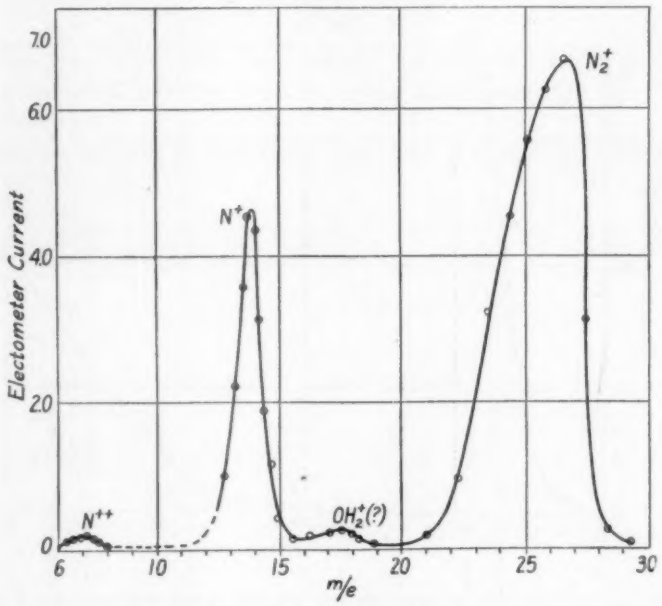
where W is the ionizing potential. Clearly the width of the peak is proportional to $\frac{xV_2}{V_2+V_3}$. Also, since the greatest probability of collision will be near E_1 and taking probability of ionization proportional to $\frac{V-W}{V}$, the greatest number of ions will be produced near E_1 so that the peak will not be symmetrical but will fall off more gradually for higher V_3. This consideration may be modified somewhat by the greater chance of ions produced near E_2 getting through the slit. If the greatest number of ions come from some point between E_1 and E_2, the $\frac{1}{V_2+V_3}$ scale will give too small a value of m/e and the error will be much greater for peaks where V_3 is of the same order of magnitude as V_2.

Now let us consider secondary effects such as might be caused by production or modification of ions by collision with other ions or molecules. Suppose that the ions formed by the primary electrons are X^+_2 but that they may be converted at any point along their path into $X^+ + X$ by collision with another molecule. If this occurs anywhere between E_1 and E_2, a peak will result at a value of $\frac{1}{V_2+V_3}$ appropriate to ions of $m/e = X^+_2/2$ and this peak will be nearly as sharp as if the X^+ ions were a primary product, but should be slightly shifted toward larger values of V_3. The same remarks apply to any new ions produced by these secondary collisions. For conversions of X^+_2 to $X^+ + X$ occurring between E_2 and E_3 or for new ions produced there, the V_3 required to give the new ions the necessary radius of curvature in the magnetic field will vary rapidly and continuously so their effect will merely be to increase stray current between peaks. For collisions between S_2 and S_3, on the other hand, the case is different; the X^+_2 ions have now fallen through the entire electric field but do not enter the magnetic field until they pass S_3. If they are to enter at S_2 as X^+_2 and emerge at S_3 as X^+ and yet be bent around to P, they must have fallen through a potential drop $V_2 + V_3$ four times as great as would be necessary for ions which remained X^+_2 throughout, since for the same radius of curvature their velocity must be twice as great. Moreover, since a conversion anywhere between S_2 and S_3 would have the same effect, a peak might be expected at an m/e value 1/4 that for X^+_2. In the above argument the assumption that the velocity is unchanged by the disruption may satisfy both the conditions of conservation of energy and of

momentum. Similar reasoning may be applied to conversions of different primary ions and may include secondary associations as well as dissociations if it be remembered that the energy and momentum conditions are more complicated in the case of association.

It may seem absurd to suppose that ions can be disrupted by collision between S_2 and S_3 and yet retain their speed and direction sufficiently to get through S_3 and around to P. A much more

FIG. 6.



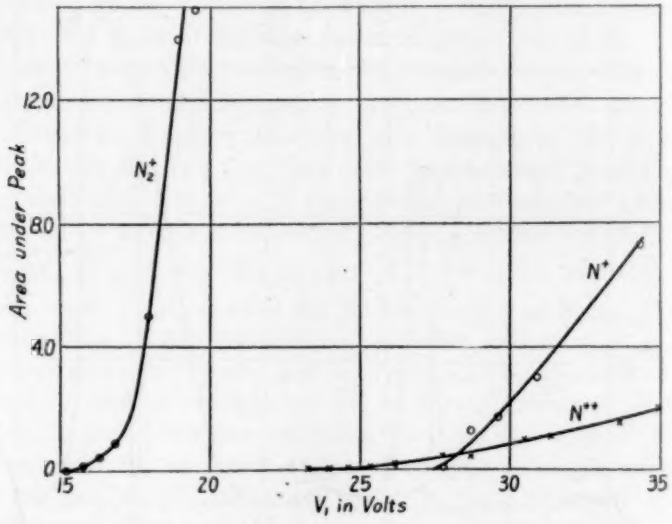
V_1 = 100 volts; V_2 = 40 volts.

natural supposition is that any collision in this region merely scatters the ion out of the beam so that it never gets to P at all, no matter what its velocity on passing S_2. This was the position taken by the writer up to very recently, but in the light of the latest results on hydrogen it seems untenable. It is hoped that the completion of the experiments now under way will clear the matter up. The reason for discussing the point at such length here will become apparent when we come to consider some peculiarities in the results on nitrogen, oxygen and hydrogen which will now be presented.

RESULTS ON GASES.

Nitrogen and Oxygen.—In Fig. 6 is given a curve which is typical of the results obtained in nitrogen. The m/e scale was obtained by assuming the value 14 for the peak marked N^+. It is seen that there are four maxima at m/e, 7, 14, 18 and 27. That at eighteen was found due to the presence of water vapor while the other three were due to nitrogen and were attributed to primary ions of the forms N^+_2, N^+ and N^{++} as indicated in the figure. The variation of the intensity of these peaks with V_1, the speed of the

FIG. 7.



impacting electrons, gives curves of the type shown in Fig. 7. Obviously, the dominant product of ionization is the molecular ion, and it is the only product for several volts above the first ionizing potential. This is not altogether unexpected, but the surprising result is that the doubly charged atoms are apparently formed at lower voltages than the singly charged atoms.

In oxygen the results were very similar to those in nitrogen, though the peak due to O^{++} was less reproducible and appeared at only slightly lower voltage than the O^+ peak. In both nitrogen and oxygen the critical potential for the molecular ion was identified with that recorded by other observers and values were assumed which were compared with the experimental values to

get voltage corrections for the higher critical potentials. These results have been presented and discussed in detail elsewhere.[6] The final values with estimated probable errors are given in Table I.

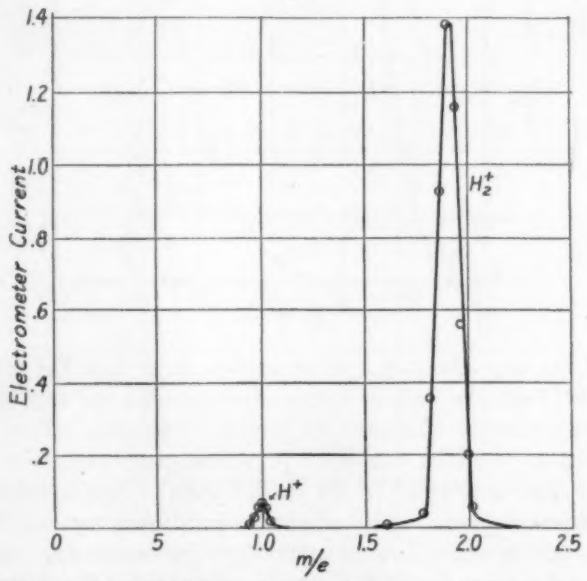
TABLE I.

Type of Ion.	Critical Potential. Nitrogen.	Oxygen.
Singly charged molecule	16.9	15.5
Doubly charged atom	24.1 ± 1.0	22.5 ± 0.6
Singly charged atom	27.7 ± 0.8	23.0 ± 0.3

The possibility that these effects are not all due to primary ionization will become evident when the results on hydrogen are presented.

Before turning to hydrogen, however, it should be mentioned

FIG. 8.



$V_1 = 40$; $V_3 = 40$ volts; $H = 1075$ gauss; $i = 655$ microamps; $p = 0.0000 \rightarrow 0.0002$ mm.

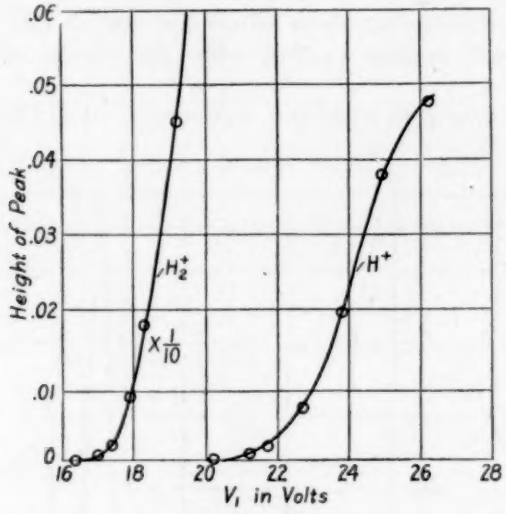
that experiments in nitrogen and oxygen were also done in which values of V_1 as high as 700 volts were used. These indicated a sharp change in the relative intensities of the different ions at

[6] *Proc. Roy. Soc.*, **104**, 121–134, 1923, and **105**, 116–128, 1924.

about 400 volts for nitrogen and somewhat higher for oxygen, though it was impossible to reproduce observations satisfactorily in this region. The number of molecular ions fell off sharply, while at the same time the atomic, particularly the doubly charged atomic, ions increased.

Hydrogen.—As is clear from the typical curve shown in Fig. 8, the molecular ion is even more dominant in hydrogen than in oxygen and nitrogen. Moreover, it was found from curves like that in Fig. 9 that the minimum potential for the detection of

FIG. 9.

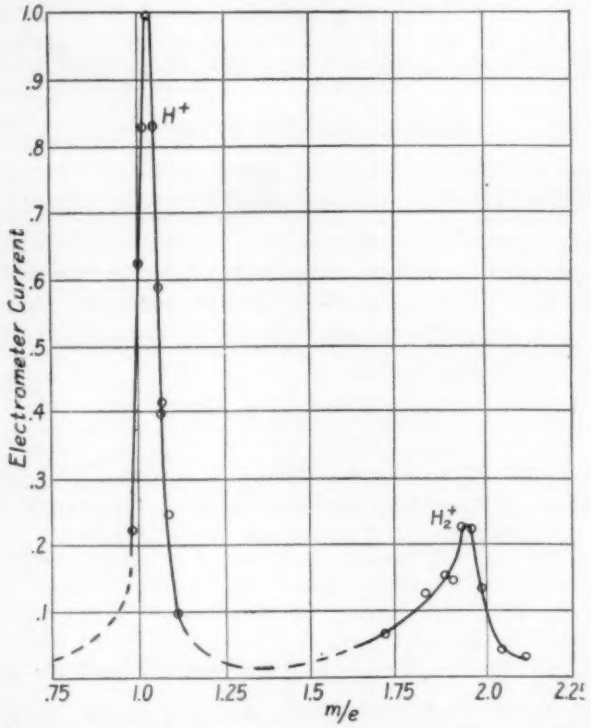


atomic ions was about 4.2 volts higher than that for molecular ions, and that the latter point corresponded to the generally observed ionization potential of about 16.5 volts. This is very surprising as the idea has been prevalent that ionization at this potential was accompanied by dissociation. Apparently such a dissociation is a secondary effect, as is shown by the curve in Fig. 10, which was taken at such high pressures that secondary collisions between E_1 and E_2 were probable.[7] Further, at this pressure, the maxima due to H^+ persisted down to the same volt-

[7] It should have been mentioned in the original report of this work that Dempster observed a similar variation of relative intensity with pressure but was working at eight hundred volts, so that conditions were hardly comparable. (*Phil. Mag.*, **31**, 438–443, 1916.)

age at which the H^+_2 disappeared. This suggested the possibility that the observed disappearance potential for H^+ might not really represent a critical potential but might be due to secondary atomic ions whose numbers first became detectable at this point. The detailed bearing of the results on this question has been considered elsewhere [8] and the point is under investigation once more at the

FIG. 10.



$V_1 = 20.7$; $V_2 = 20.7$ volts; $H = 800$ gauss; $i = 480$ microamps; $p = 0.0042 \rightarrow 0.075$ mm.

present time. Preliminary results of this new investigation confirm the occurrence of secondary effects at high pressures but indicate that they are more complicated than was supposed. Both atomic ions and triatomic ions occur and increase relative to the H^+_2 with pressure, but in some cases one is much stronger and in some cases the other. The conditions determining which shall predominate are still a mystery at present writing.

[8] *Proc. Roy. Soc.*, **105**, 116–128, 1924.

Another very important new result is the observation of secondary effects due to collisions in the region between S_2 and S_3 such as were discussed in an earlier part of this paper. Small peaks are observed at $m/e = 1/2$ and $m/e = 1/3$ apparently due to the conversion of H^+_2 and H^+_3 to H^+ between S_2 and S_3. So far these secondary effects have been studied only at considerably higher pressures than those used in oxygen and nitrogen. Nevertheless they introduce some element of doubt as to the previous interpretation of the "doubly charged atomic" peaks. It is hoped that further experiment will clear this away.

GENERAL DISCUSSION OF RESULTS.

When the results presented are considered, one important principle emerges. In all three diatomic gases studied, the first ionization potential corresponds to ionization without dissociation. Moreover, if an impacting electron ever causes dissociation simultaneously with ionization, it is first able to do so at such a high voltage that the transition cannot be represented by such a thermochemical equation as

$$X_2 + D + J_{X^+} \longrightarrow X^+ + X$$

where D is the heat of dissociation and J_X the ionizing potential of the atom. It would be possible to explain the critical potential for N^+ by an equation of the form

$$N_2 + D + 2J_{N^+} \longrightarrow N^+ + N^+$$

which would be satisfied for $D = 6$ volts and $J = 11$ volts, reasonable values. But in oxygen and hydrogen where we know the values of J and D approximately, there is no agreement whatever. We are forced to the conclusion, therefore, that at least for homopolar compounds it is not possible to apply thermochemical equations to these transitions caused by electron impact. Needless to say, this invalidates any deduction of heats of dissociation from ionization potential experiments.

The evidence on the applicability of thermochemical equations to similar phenomena in heteropolar compounds is conflicting. It is hoped that this problem can be settled by studying such substances with the method described above. Indeed, it

is felt that there are many problems to which this method can be applied. For example, the secondary effects just obtained in hydrogen suggest a whole series of experiments on the dissociation and association of ions by molecular impact. Such studies may perhaps throw light on the questions of the mechanism of ionization and of molecular structure which are beginning to have so much fascination and importance at the present time.

Surface Tension of Colloidal Solutions and Dimensions of Certain Organic Molecules. P. LECOMPTE DU NOUY. (*Phil. Mag.*, Aug., 1924.)—He uses an instrument, based on Weinberg's work, that measures the surface tension at short intervals of the same solution and not the property of a layer continuously renewed. "The torsion of a wire controlled by a worm gear is used to counteract the stress of a liquid film adhering to a platinum ring, and as the amount of torsion can be measured by a simple reading on a dial, the surface tension is measured directly. The measurements require only 20 seconds." Thirty-eight thousand measurements were made. Such colloids as blood serum, pure albumin and gold, silver, copper and iron sols show a decrease in surface tension with the passage of time. For example, pure rabbit blood serum drops from 59.5 to 56.0 in seven minutes. The change follows an exponential law and "is due to the adsorption in the surface layer, in function of time, of the molecules in suspension." The decrease amounts to about one dyne during the first minute. It grows larger with the dilution of the solution and reaches a maximum for concentrations between 10^{-4} and 10^{-5}. "Certain colloids, saponin, for instance, do not show any drop at high concentrations, but even a slight increase (10^{-1} to 10^{-3})." Even slight stirring causes the surface tension of the solution to rise though not to its initial value. This result may be obtained several times.

In the case of some organic colloids a study was made of the initial surface tension and of its value two hours later. In every instance there was for some concentration a clearly marked maximum in the decrease observed. For sodium oleate this concentration for maximum change was 1/750,000; for serum 1/10,500. The author gives an explanation of this based on the formation of a monomolecular and oriented layer at the particular concentration corresponding to maximum change. "Should the above assumption of the existence of a homogeneous oriented monolayer at a given concentration be well founded, the rate of evaporation of such a solution should be slower than that of any other concentration. Water molecules would not escape so freely from a solution covered with such a film. At a higher concentration, we have assumed that there is a piling up, and no organization of the molecules. Therefore, the water molecules

can pass between and escape more easily than through a closely fitting mesh of identically oriented molecules. At lower dilutions the breaks in the film would allow the normal process of evaporation to take place." A test was made with blood serum of six dilutions placed in watch-glasses and there evaporating. These are the results:

Dilutions.	.1	.01	.001	.0001	.00001	.000001
Diameter after 6 hours' evaporation, mm.	26	27	27	30	27	26
Diameter, 30 minutes later	20	20	23	26.5	23	22
Diameter, 1 hour later	0	0	6	14	0	0

A second series of experiments confirmed .0001 as the dilution of slowest evaporation.

The author applies his discovery of a criterion of the existence of a monolayer, *i.e.*, the attainment after waiting of a minimum of surface tension, to the computation of molecular dimensions in this layer one molecule thick. He calculates the molecule of crystalline egg albumin, molecular weight 34,000, to be 52.8×10^{-8} cm. long and the square root of its cross-section to be 29.2×10^{-8} cm. For sodium oleate, molecular weight 304, the corresponding results are 12.3×10^{-8} cm. and 6.8×10^{-8} cm. "If we compare these figures with the dimensions of the molecule of oleic acid given by Langmuir (length, 11.2×10^{-8}; square root of cross-section, 6.8×10^{-8}), we see that the diameter of the molecule is unchanged, but that its length is increased by 1.1×10^{-8} cm. This would correspond to the space occupied by the sodium atom at the end of the molecule."

The presence of as little as a millionth part of most colloids affects the crystallization of NaCl and other salts. Large crystals do not form in the presence of traces of colloids, but, at least in watch-glasses, the crystals separate in rings. G. F. S.

The Relation between Tarnishing and Corrosion.—Allied to the subject of corrosion, which is commonly understood to mean a rather marked destruction of the surface of a metal, is the phenomenon of tarnishing which is a superficial development of the compound of a metal generally regarded as an oxide, but in the more or less polluted atmosphere of industrial districts other elements may act. Tarnishing of silver by sulphur has long been known. Water, as might be expected, promotes the action of tarnishing agents. Iron and zinc are unattacked by dry sulphur dioxide, but a very small amount of water vapor causes marked action. Dry copper exposed to dry hydrogen sulphide assumes a series of tints resembling that of mother-of-pearl or a soap bubble, which suggests the formation of a thin sulphide film in optical contact with the metal. This film, however, is modified in the presence of a material amount of water.

The paper from which these data are taken is by U. R. EVANS, of Cambridge, England, and part of the *Proceedings of the American Electrochemical Society* at its October meeting. H. L.

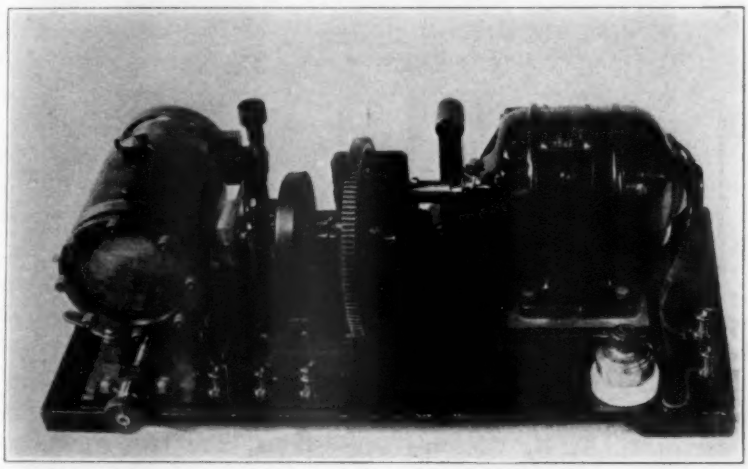
THE OPTICAL PROJECTION OF THE TRACKS OF ALPHA PARTICLES.*

BY

H. T. PYE.

THE well-known expansion apparatus due to C. T. R. Wilson, admirable as it is for photographic purposes or for visual use by a few observers, does not lend itself readily to projection so that a large audience may see the tracks of α-particles. The same is

FIG. 1.



true of the Shimizu modification of Wilson's apparatus. Reflectoscope methods have so far not proved practicable.

The writer has devised a modification of the Wilson-Shimizu apparatus so that light from an arc lamp passes through the expansion chamber and the shadows of the tracks are clearly shown on a screen by the usual projection methods.

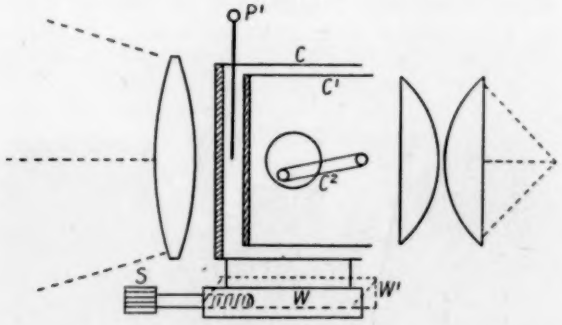
This apparatus in its first immature stages was originally shown to many members of the British Association at the Macdonald Physics Building at McGill University early in August. It has since received one notable improvement. At first the axis of the cylindrical expansion chamber was horizontal and

* Communicated by Dr. A. S. Eve, Associate Editor.

the clouds, falling under gravity, appeared to move upwards on the screen as soon as they were formed. By placing the axis vertical, and using a plane mirror for reflection at 45°, this undesirable feature has been removed.

If the active deposit of radium is placed at the end of a thin rod so as to be in the middle of the expansion chamber, then the appearance on the screen is somewhat similar to Fig. 3, which, as a matter of fact, is a snapshot of the rays in the expansion chamber itself. The tracks are not straight because the ions and droplets had begun to disperse, and because convection currents

FIG. 2.



were present in the chamber; also there was too much radium on the tip of the rod.

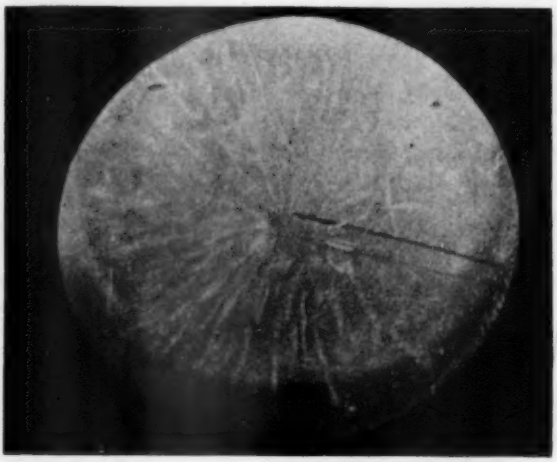
Various improvements are still in progress, but it will be seen that the general scheme is that of the Shimizu apparatus, and that many of C. T. R. Wilson's suggestions have been found of great value.

Fig. 1 is a photograph of the actual apparatus and the main scheme is indicated in Fig. 2.

C is a hollow brass cylinder with a plate glass cover. C^1 is a hollow brass piston (also with a plate glass cover) to which a reciprocating motion is given by the crank C^2. This crank gives a constant stroke of 11 mm., but in order to vary the expansion ratio the cylinder *C* can slide in the ways *W* and and W^1 by means of the screw *S*. The piston is driven by a one-eighth horsepower electric motor through a pinion of five leaves and a gear of 120 teeth, giving a maximum of 70 strokes a minute, which of course can be reduced by a rheostat in circuit if desired.

The cylinder glass is well insulated from the rest of the apparatus, while the surfaces of both of the inner faces of the glass plates must be made conducting with a mixture of clear gelatine and dissolved copper sulphate, following C. T. R. Wilson's recommendation. A difference of potential of 200 volts between these surfaces is used to remove the clouds after their formation on the ions caused by the respective α-particles. The expansion chamber is sealed tight with rubber washers and screws,

FIG. 3.



after some moisture has been introduced, the piston being then at the inner end of its stroke. It is inadvisable to use radium because the emanation (radon) causes contamination. Hence radium C, or polonium, or thorium C is more suitable.

If fine needles are introduced, facing one another, connected to a Wimshurst machine, it is also possible to project the spark discharge effects at various potentials and distances.

An arc lamp of about 1500 candlepower is sufficient, but a water or alum cell is placed near the lantern condenser in order to cut down the heat entering the expansion chamber; also to prevent the lubricant, vaseline and beeswax, between cylinder and piston from a tendency to "run" if too warm.

In the demonstration from which the photograph of Fig. 3 was taken, the projection on the screen was about six feet in diameter when the apparatus was about thirty feet away, and in

a room well darkened the shadows of the tracks were visible to a distance of about forty feet or more.

I have to thank Mr. S. Amesse for the photographs.

NOTE BY DR. EVE.

This apparatus when well developed is likely to have a large and important vogue for popular audiences and for instructional purposes; possibly it may have its uses for research work also. As the scheme for projection was entirely worked out by Mr. Pye, I suggest that the apparatus be called the "H. T. Pye Projection Modification of the C. T. R. Wilson-Shimizu Apparatus." The projection on the screen is excellent and much superior to that indicated by Fig. 3.

The Internal Composition of the Earth. ROKURO YAMAMOTO. (*Ann. de Phys.*, May, June, 1924.)—In endeavoring to find what is the character of the depths of the earth there are two chief ways to proceed. The first is that of the geologist who, like a physician making a diagnosis, from appearances on the surface infers the condition of the interior. The second is that of the seismologist who seeks information from the only messenger that traverses the interior of our planet, the wave coming from an earthquake. In his own country of Japan this seismologist has had all too much occasion to learn of these waves at first hand. "I had opportunity," he says, "at the time of the great catastrophe that ravaged Japan on September 1, 1923, to verify my formula whose justification seems to me to be established." With fine literary art, with a knowledge derived from observation and with strong feeling attained through bitter suffering, he sketches in a page an outline of the meaning of earthquakes to the human race, and makes his readers feel his sincerity when he states, "It is not, however, with the sole end of establishing more accurate results than those hitherto possessed that I have undertaken this work. To combat effectively an evil, it is necessary before all else to recognize its manifestations, and every piece of work that can some day aid us in protecting mankind against these sudden convulsions of the globe seems to me to be of unquestionable usefulness."

Wiechert, in 1897, proposed his theory that the earth has a central core of iron, so that somewhere between the surface and the centre the density of the earth has one or more discontinuities of value. In this paper the basis of this theory is scrutinized and fundamental errors are discovered. The author therefore rejects the conception of an earth with sudden changes of density, confirming his conclusion by an appeal to celestial mechanics which has long found difficulty in reconciling Wiechert's theory with the facts of nutation and precession. G. F. S.

THE INTERRELATIONS OF MODERN PHYSICS AND MODERN PSYCHOLOGY: A REPLY.*

BY

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IN HIS lecture on this subject [1] Dr. Troland makes many assertions about physics which, as a practitioner of that science, I cannot accept. His errors (as they appear to me) are not new; they occur in almost all discussions of science by philosophers. Protests against them are equally old; they occur in almost all discussions of science by scientists. The repetition of the errors must be an excuse for a repetition of the protests. Dr. Troland, it is true, claims to be a modern psychologist rather than a philosopher; but since in this matter modern psychology appears to me indistinguishable from ancient philosophy, and since psychology (as I shall explain presently) has another meaning, I propose throughout to substitute "philosopher" for Dr. Troland's "psychologist."

1. THE TWO FEATURES OF EXPERIENCE.

Dr. Troland starts by considering "experience," and comes to the amazing conclusion that the physical thinker is not interested in experience in itself or for its own sake. I might reply that, as a physicist, I am interested in nothing but experience, and that my interest is distinguishable from that of the philosopher (and mathematician) by being devoid of any ulterior object. But the real issue is perhaps better stated by suggesting that experience has two aspects, one of which interests the philosopher and the other the physicist. The feature of experience which interests the philosopher is its variability and inconsistency. My experience varies and it is different from yours, both in content and nature; I experience different things and, even when I experience the same things, there is an important distinction between my experiencing them and your experiencing them. This feature leads common sense to distinguish between a subject and an object, between which experience is a relation, and might inspire (I am

* Communicated by the Author.

[1] JOUR. FRANK. INST., 197, 479, April, 1924.

not so rash as to say it has inspired) such abstruse disquisitions as those with which Dr. Troland opens his lecture.

On the other hand, the feature of experience which interests the physicist (and the student of any other natural science) is its invariability and consistency. In spite of the difference between my experience and yours, there is a common element which enables me to communicate with you and share a common practical life. The task of physics (and other sciences) is to sort out, to order, and to render intelligible this element common to all experience. The method of ordering is by the discovery of invariable associations of elements of experience which are appreciated by, and valid for, all beings with whom we can enter into communication, and whose experience we can ascertain. A given element of experience must always be individual and "subjective"; it must always have a different validity for different "subjects." Yet all "subjects" may realize that one element A is invariably associated in their experience with another element B. If such groups, consisting of A and B in invariable association, can be found, they will have the same validity for all "subjects," they will be objective.

Such groups can be found. The description of the groups and the statement of the invariable associations of their components are the laws of science. They are often not stated explicitly, but implied by the use of certain words. All the technical terms of science, most of the grammatical nouns and verbs it uses, and many of the other parts of speech, imply the invariable association of certain elements of experience; we should not speak of an electric current unless the phenomena discovered by Ampère and Faraday were invariably associated; we should not speak of water unless the properties we attribute to that substance were invariably associated. It is a mere historical accident that some, but not all, statements of invariable associations have come to be made explicitly in the grammatical form of a proposition and have come to be termed "Laws"; it is an unfortunate accident, because the complete divorce between the meaning and the grammatical form of scientific propositions is a continual source of misunderstanding by those who regard the work of science from the outside.

Dr. Troland is very clearly a victim of this misunderstanding. "Science," he says, "is essentially a system of words or symbols."

That may be true, if rightly interpreted. To know fully the meaning of all scientific technical terms is to know all science; the propositions of science are implied in the meanings of its terms. But when he goes on to say that "the meanings (of the words or symbols) could not be combined into a science without the words," he is very far from the truth. In science the meaning always precedes the word; the words are invented (or adapted from common use) to state some proposition already discovered. Science is distinguished from mathematics and formal logic by using language, not as an instrument of thought, but as a mere device for registering conclusions. In this our prehistoric ancestors who invented our language were typically scientific; they did not say "tree" or "water," and then look around for something to give a meaning to the words; they invented the word when the meaning was already in their minds. The only change that conscious science has made in this procedure is the more careful choice of the elements of experience for which it invents words.

2. THE PROPERTIES OF SUBSTANCES.

Such a very summary account of the attitude of physics towards experience is enough to solve the ancient difficulties concerning "primary and secondary qualities" which Dr. Troland has dragged once more into the light of day. Let us take his example of color. An alchemist would have spoken of "blue vitriol," meaning that there was a substance among the properties of which were included (*a*) a certain crystalline form, (*b*) certain chemical reactivities, (*c*) the power of evoking a certain indescribable but definite visual sensation similar to that evoked by the blue sky. Now from the common sense conception of a substance, science has developed one of the most important of the invariable associations by means of which it orders experience. The scientific conception of a substance differs from the pre-scientific conception mainly in the substitution of complete for incomplete invariability. The alchemist's blue vitriol is not a scientific substance at all, because the associations by which he defined it are not truly invariable. Those implied in the description of crystalline form are the least variable, and scientific investigation has done little more than refine them by the introduction of measurement. Those described as chemical properties are more

variable; the tests by which an alchemist would have identified blue vitriol would not satisfy a modern analyst, whose wider and more complete knowledge of laws is indicated by the name "copper sulphate." Those described by the adjective "blue" are the most variable of all. No conscious scientific investigation, but only such casual observation, as even philosophers may make, is sufficient to show that in the dark, or when a red glass is interposed, or even to persons with abnormal vision, the sensation of blue is not associated with the other properties. And here again scientific investigation has replaced a variable by an invariable association. When we speak of the color of copper sulphate nowadays, we are not referring to immediate visual sensations but to a spectrophotometric comparison of the light incident on the crystals with the light reflected from them. This comparison can be made by a color-blind person just as well as by one with normal vision; with suitable apparatus it could even be made by one totally blind; it could be made even when a red glass is interposed so long as the glass does not absorb all the radiation lying within the absorption band of the substance; and if it cannot be made in the dark, that is only because the very meaning of color to modern physics implies that the test should not be made in the dark. Color determined on spectrophotometry is wholly free from the variability of color based on direct visual sensation; it is as invariable as crystalline form. It has all the characteristics which distinguish a "primary" or "objective" property from a "secondary" or "subjective" property. And not only is the property itself independent of the conditions of observation (so long as they are such that the property, as defined, may be ascertained at all), but it is also in truly invariable association with the remaining properties; the absorption band of copper sulphate is as characteristic as its crystalline form or chemical reactions. In this case, as in all others, invariable associations are discovered and laws can be formulated when, and only when, primary properties have been substituted for secondary or, more generally, objective for subjective experience.

It is therefore ridiculous to suggest that the distinction between primary and secondary properties presents any difficulty to science, or that it has been accepted by physicists reluctantly. It is a characteristically scientific distinction, on the recognition of which all

science depends and the detailed investigation of which leads to the discovery of an important class of laws. For science, only primary properties are properties at all; if we sometimes include among a list of properties a name (such as color) which common sense attaches to a secondary property, it is only because we have changed entirely the meaning of the name. The old term "color" may be useful as a reminder that physical color, the primary property, has some affinities with visual color, the secondary property; but its use has no more significance than the description as "chemical" of experiments which no alchemist could ever have imagined.

3. PHYSICS AND PSYCHOLOGY.

Dr. Troland would probably accept all this and say that it merely confirms his contention that "color (*i.e.*, visual color) has been definitely relegated to psychology." If he means by psychology the study of such questions as he discusses in his lecture and not those which arise in the formulation of scientific laws, his conclusion is entirely false. For there are forms of invariable association other than that of the properties of a substance, and the fact that visual color is not a property of a substance does not mean that it is beyond the range of experimental science or that there can be no scientific laws concerning it. We already know several invariable associations in which color visual is concerned; it is invariably associated (in conjunction with physical color and other elements of experience) with the intensity of the light, the previous or concurrent visual experiences of the observer, and with certain properties of the observer himself. These associations are just as objective as that of physical color with the other properties of a substance. If A is color-blind and B normal, the associations involving A's color perceptions will be different from those involving B's; but both associations may be objective, just as it is possible that one objective association may involve the physical color of copper sulphate and another that of sodium sulphate. All that is necessary for objectivity is that the fact that A and B have certain perceptions in certain circumstances should be valid for both A and B and everyone else. A knows his perceptions immediately; B can judge them only through his words and actions; but so long as both agree (as they actually do) what perceptions A has when placed in certain conditions, the

invariable association between those perceptions and those conditions is as valid for one as for the other. The law does not involve any of those elements which give *A*'s perceptions peculiar validity for *A;* it involves only the bare fact that the perceptions occur.

Concisely (but of course not quite accurately) we may say that, while physical color is the property of a substance, visual color is the property of a person.[2] And just as chemistry might be roughly defined as study of the properties of substances, so there might be definable a science which should be the study of the properties of persons. Such a science would be quite fitly called psychology; for while the associations we have just discussed are between the property of a person and other things which are not properties of persons, some invariable associations are (I believe) known between two properties of the same person; and these associations are universally recognized as psychological. The problems of the interrelations of physics and such a science of psychology would be similar to those of the interrelations of any other two sciences; they would arise, not from conflict, but from overlapping and from the merging of one into another. The question whether color is to be "relegated to psychology" would be exactly similar to the question whether radio-activity is to be "relegated to chemistry"; it would raise many personal but no scientific difficulties. But such psychology is not that of which Dr. Troland speaks; his main thesis is the difficulties of reconciliation. His psychology is not a science; it does not start from the examination of invariable associations. To such a study no physicist would ever relegate anything which had once been brought within the scope of science.

Dr. Troland's remarks about the "c.g.s. system" are more original; but they are based on a mere misunderstanding and can be dismissed very briefly. He apparently imagines that mass, length and time are chosen as magnitudes to which arbitrary units are to be assigned because they are characteristically primary. That is quite wrong; all magnitudes are necessarily primary in

[2] Or rather of a class of persons; for departures from normal color vision are shared by many individuals. It is an interesting question whether peculiarities of vision discoverable in one individual only could form the subject of a science; the question must probably be answered on the lines of the discussion of individual objects in my "Physics," pp. 81–85.

the sense I have just discussed; they could not be measured if they were not, for measurement depends on laws. The only important distinction between magnitudes is that between fundamental and derived, that is to say, between those which (like length) can be measured without measuring anything else and those which (like acceleration) can be measured only by measuring some other magnitudes. One reason for the selection of mass, length, and time as primary units is doubtless that they are all fundamental magnitudes; but this cannot be the only reason. Personally I think that the choice is as arbitrary as the preference of the centimetre as against the inch. But so long as it is clear that the reasons, whatever they may be, are detailed and technical and in no way fundamental, we need not stop to consider them here. Perhaps the argument most likely to convince Dr. Troland is that mass, length, and time are not the only magnitudes of which the units are fixed arbitrarily; temperature is another, and he would presumably class temperature as secondary.

4. LAWS AND THEORIES.

All that I have said so far applies only to that part of science which consists of laws; there is another part which consists of theories. Much of Dr. Troland's account of theories is quite correct. It is quite true that when we explain laws by theories (for example, the laws of the reflection of light by the electronic theory) we are substituting for the purely empirical conceptions of laws other conceptions that are not purely empirical. An electron has never been observed in the sense that material bodies are observed; it is not the expression of an invariable association of elements of experience; it cannot be described in terms of observation alone. Again it is true that the substitution of non-empirical for empirical conceptions is made according to a "logical and (if you like it) artificial scheme" which "enables us to predict certain details of experience" from an examination of the non-empirical conceptions of the theory. But he overlooks two very important features of theories.

The first is that the theory is inseparable from the laws that it explains. It is quite untrue that "the empirical notion of mass departed with the advent of the electrical theory of matter," or that "empirical space and time were quite ousted by the principle

of relativity." Laws do not lose their importance for science because they are explained by a theory; rather they gain importance, because they cease to be merely empirical. Dr. Troland has only to open the first physical journal that comes to his hand to realize how completely mistaken is his assertion. He will find discussions of the electrical theory of matter based on experiments which involve essentially the measurement of mass, and that the proofs of the principle of relativity are based on experiments which necessarily involve measurements of empirical space. The conceptions of the laws explained by a theory are quite as important a part of the theory as the conception by means of which it is explained; a theory divorced from all laws means nothing whatever; it is a mere jumble of words. To forget this is the favorite blunder of philosophers (and of many mathematicians). They should remember that a proposition, even if it involves explicitly the conceptions of a serious theory, has no scientific significance unless, by means of the "logical and artificial scheme," it can be interpreted in terms of experimental conceptions. It is probably hopeless to stop the flood of speculation, uncontrolled by experiment, of which Einstein's scientific work has been the innocent cause; but it is adding insult to injury to suggest that it has anything whatever to do with science.

The second feature of theories which Dr. Troland overlooks is that they explain. If theories consisted of nothing but the "logical and artificial scheme," there would not be the smallest difficulty in framing a theory to cover any desired range of laws. The invention of theory, now the highest branch of the scientific art, would be a mere exercise in formal logic on an intellectual level with numerical computation. The purpose of the substitution of the non-empirical for the empirical conceptions is to explain; and the criterion which enables a distinction to be made between wholly worthless theories and those which deserve serious consideration is the fulfilment of this purpose. When a theory satisfies this condition, we may proceed to investigate whether it serves also the secondary purpose of prediction. It is a remarkable fact that so many theories, selected in the first instance because they explain known laws, are actually found to predict laws that were previously unknown. But the test of prediction is subsidiary; it may be true that no theory has ever been ultimately

established which did not actually predict; it is quite certain that no theory has ever been entertained at all which did not explain.

5. PHYSICS AND PHILOSOPHY.

Now explanation is "subjective." It implies that the ideas of the explanation are more comprehensible than those of the thing explained; and concerning comprehensibility different persons will never agree. The laws of science are equally valid for all persons; if they were not, they would not be laws. But the theories of science are not equally valid. Dr. Troland seems to recognize this when he admits that "physical theory presents us with an account of the world couched in terms that we cannot understand." But he does not seem to realize that the converse of this proposition is true. Just as philosophers do not understand characteristically physical conceptions, so physicists do not, in general, understand characteristically philosophical conceptions. The crudity which he finds in the enouncements of some physicists is merely due to his attempt to substitute in scientific propositions philosophical conceptions, which he understands, for scientific conceptions, which scientists understand.

When physicists speak of a "real world" or of "objects existing," they are not referring to the philosophical conception of reality or existence at all. Real or existent things for the physicist are those concepts which satisfy completely his intellectual instincts, that is to say, either the concepts of laws or the concepts of theories which explain those laws.[3] When they say that material objects or electrons are real or, possibly, the only real things, they are not enouncing the philosophic doctrine of materialism. They are not asserting that the concepts valid for science are valid also for philosophy; they are merely asserting that they are valid for science. The "cruder" the physicist, the less likely he is to fall into the error (as Dr. Troland doubtless holds it) of materialism; for the less ready he will be to admit that any considerations outside the boundaries of science can possibly be relevant to the validity of any scientific conception.

Doubtless many physicists, as well as many philosophers, fail to recognize the fundamental distinction between physical and philosophical reality; perhaps some of them will be indisposed to admit that scientific reality has not necessarily any validity for

[3] Not all scientific concepts are "real," but only a special class of them. I have discussed this matter in detail in "Physics," Ch. IX.

philosophy, and will be more inclined to maintain that philosophers are simply in error in denying that validity. But it is not a question of truth or error; it is a question of sense or nonsense. If Dr. Troland's "universe" were the physical universe, his statements about the "logical structure of the universe" would not be merely untrue; they would be meaningless; the physical universe can no more have a logical structure (as if it were a proposition) than an electron can have a color. If his "concrete substance" were our substance, it would be as sensible to say that science gives no information about it as to say that a black cat is not black. The only alternative to accusing all philosophers of complete imbecility is to recognize that they are using words in different senses from our own. Let us be as wise as philosophers in recognizing that some ideas are beyond our grasp, and wiser in refusing to discuss them.

The Measurement of Small Radio-activities. G. HOFFMANN. (*Zeit. f. Physik,* Vol. 25, No. 3.)—An electrometer of high sensitiveness registers photographically the current caused by the radio-active action of the substance under examination in carbon dioxide at a pressure of 1300 mm. mercury. At the end of each hour's registration the mirror of the instrument is brought back to its zero point to begin its course for the succeeding hour. The conductivity of the gas is due to the joint action of the beta and the gamma rays on the one hand and to the alpha rays on the other. So long as only the former are present, the photographic trace runs along quite smoothly. When, however, one of its rare alpha particles is ejected by the slightly radio-active substance, there is a sudden increase in the conductivity of the gas and the curve rises at once. By examining the curve for an hour, it is possible to count the number of alpha particles registered in that period, while the general placid course of the curve furnishes information in regard to the conductivity credited to the two other types of rays. By the method used the number of alpha particles was reduced to from three to five per hour. It appears that the alkalies, K, Na, Rb and Cs, emit no such particles. Sodium emits no radiation of any kind, but the remaining three do send out rays that ionize the gas. Gram for gram, uranium emits radiation 460 times as strong in current production as potassium, and 112 times as strong as cæsium. Rubidium shows but a trace of radio-activity. Lead a century or two old was no more productive of alpha rays than copper, but recent lead sent out about ten times as many of these particles as copper. The author attributes this latter effect to the presence of the isotope, RaD. He further finds that fluorspar from Bohemia seems to have a radium content about eight times as large as that of the same mineral from the Harz region in Germany.

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

MEASUREMENT OF HEAT INSULATION AND RELATED PROPERTIES OF BLANKETS.[1]

By P. D. Sale and A. F. Hedrick.

[ABSTRACT.]

THREE sets of apparatus have been described for the purpose of standardizing methods for testing the "comforting" value of textile fabrics. Heat insulation is measured in terms of thermal resistance, as expressed by the simple equation $R = J \triangle T/I^2 \Omega$, where R=thermal resistance = (number of degrees centigrade temperature difference, between the specified surfaces of a specimen, required to produce a heat flow of 1 calorie per second through a test area of 1000 cm.^{2}) and $J = 4.183$, electrical equivalent of heat, ΔT = temperature drop through the test specimen, I = current flow in circuit of electrical resistance Ω. This test is made with the specimen exposed on the outside to conditioned air, as in use, and it is recommended that the temperature of the run (temperature of the hot plate) be 51.7° C. (125° F.).

It is pointed out that the problem, dealing with heat transfer through fabrics, is one of heat transmission rather than heat conduction. Fabrics are all relatively permeable to air and moisture and these properties may influence the passage of heat through a fabric, therefore, two other sets of apparatus are described for measuring the permeability to air and water vapor. The heat-transmission set is considered to be of primary importance and the other two tests to be auxiliary and of secondary importance. Comparison of this work with that of others shows the necessity for standardization of apparatus and methods of procedure in testing.

The heat-transmission apparatus is a duplex testing set. Either set consists essentially of two flat copper plates which are insulated from and inclose an electric-heating grid. The grid consists of a micanite core uniformly wound with constantan ribbon. Heat is supplied at a known rate to the inclosing copper plates of this test

* Communicated by the Director.

[1] Technologic Papers, No. 266. Price, ten cents.

section. To prevent heat loss from the edges of the central heater, a coplanar flat compensating guard ring heater of similar construction surrounds it, leaving a narrow air gap separating the two heaters. This guard ring is maintained at the temperature of the inner heater by means of an independent current. Differential thermocouples connected across the air gap, and attached near the corresponding edges of the top centre and top guard plates enable this temperature adjustment to be effected. When these couples indicate a zero temperature difference across the air gap, no lateral flow of heat can take place in the central plate or in the narrow air gap surrounding it. Two such sets of centre and guard heaters, placed symmetrically on opposite faces of a good insulating mount board, serve as bottom heat guards, one for the other. By this duplex assembly, guard against heat exchange between the two centre heaters is effected, as well as guard against lateral flow from centre to edge guard. Thus, when regulated by independent current adjustments in the separate circuits, the heaters are maintained at a temperature balance, and unidirectional heat flow takes place from the two main centre heaters and its rate of transfer through either of the two specimens properly mounted may be measured.

The method of procedure for measuring heat transmission consists first of mounting the specimen over the heat distributing plates under a tension of 1 per cent. of the predetermined breaking strength for warp and filling directions, then clamping the edges. Mounting the specimen under this small tension removes irregularities of thickness, due to folds or wrinkles without altering appreciably the normal structure of the fabric. Next, the apparatus is heated with a steady electric current and adjustments made until the required temperature balance is obtained. The current flowing in the centre heating grid is then measured and the resulting temperature at the bottom and top surface of the test specimen is taken. The total electrical resistance of the centre heating grid is measured once for all, because the temperature coefficient of resistance of the constantan ribbon used in its construction is negligible. These data substituted in the above equation give the thermal resistance of the test piece under the standard atmospheric conditions and at the temperature of the run.

Data illustrative of the several tests, made on new blankets representative of those to be obtained in the trade, are presented.

They are analyzed to show apparent correlations between "thermal resistance" (heat insulating value), "thickness," "weight" and "density." Two equations are given in advance which are justified by complete analysis of all data obtained to date, which it is planned to present in a subsequent publication. They are as follows:

$$R = \frac{0.00643\,W}{d - 0.0206} + R_s \text{ (densities 0.0206 to 0.0835 g./cm.}^3\text{)}.$$

$$R = \frac{0.01286\,W}{d + 0.0422} + R_s \text{ (densities 0.0835 to at least 0.23 g./cm.}^3\text{)}.$$

Where R = thermal resistance per 1000 cm.^{2} area.
W = weight in grams per 1000 cm.^{2} area.
d = density in g./cm.^{3}.
R_s = a constant (0.46) which is apparently an average surface thermal resistance for all blankets tested to date.

These equations are found to hold for typical blanket constructions tested under the recommended standard conditions, *viz.*, (1) hot plate temperature of run = 51.7° C. (125° F.); (2) temperature of room = 21.1° C. (70° F.); (3) relative humidity of air surrounding top of test specimen = 65 per cent. ± 3.

METHODS OF CALCULATING HOSIERY SHIPPING CASE DIMENSIONS.[1]

[ABSTRACT.]

METHODS for calculating the dimensions of the most suitable arrangement of hosiery boxes which will require a minimum surface area of the shipping case, using both the proposed standard inside dimensions of hosiery boxes and boxes of other dimensions, are set forth. In the Appendix, the development of the equation for a minimum surface of a hexahedron for a given volume is shown to be when with sides a, Ka, and ca, where c and K are constants, $c = 2K/K + 1$. A cube is shown to have the smallest area, and a graph shows the relation when K is assigned various values. The calculations of the most economical dimensions show the possible arrangement of the boxes and the dimensions of this arrangement. The minimum in each style is taken as 100 and the other arrangements show the percentage of additional surface required. The minimums are grouped and, in

[1] Circular No. 169. Price, ten cents.

addition, sizes are listed for the use of the manufacturer of all styles. The saving resulting from the reduction of the surface area in the construction of the case is the feature brought out by this paper.

The Emission of β- and δ-rays from a Metallic Film, and the Relation to the Quantum Theory of Scattering of X-rays. LEWIS SIMONS. (*Phil. Mag.*, Aug., 1924.)—X-rays falling on a metal plate cause the emission from its surface of photo-electrons whose individual kinetic energy equals the frequency of the incident ray multiplied by Planck's constant. In addition the author proved some years ago the presence of electrons of smaller velocity, each of which has kinetic energy less than the quantity just specified by the energy associated with the K, or the L or the M levels within the atom. There are, however, still other particles emitted. These are slower than those already mentioned and constitute the δ-rays.

The "comparatively homogeneous fluorescent X-radiation from secondary radiators," such as Se, Sr, I, Sn and Ba, fell on a thin layer of gold. A method is given by which both the rapid photo-electrons and the slow δ-rays can be measured. The intensity of each emission is plotted against the wave-length of the exciting X-rays. "It was noticed that, after suitable adjustment of ordinates, the curves could be made to coincide with each other if it could also be assumed that the X-rays responsible for the δ-rays were in each case longer than the X-rays responsible for the true photo-electrons by 0.040 Å.U. This is precisely the value given by Compton's formula, where the angle of scattering ranged over from 180° to 90°. It is therefore suggested that not only does the present experiment lend confirmation to this theory of scattering, but that it would now appear that the true rapid photo-electrons are associated with the emission of the fluorescent X-rays or the unmodified scattered rays, while the δ-rays are associated with the modified scattered rays." The formula mentioned is the embodiment of Compton's theory of the scattering of X-rays, based on the quantum theory, according to which X-rays incident on a scatterer result in the scattering of rays, the "modified scattered rays" of the quotation, that have a greater wave-length than the original rays.

Why is it worth while to call attention to an apparently abstruse agreement? Because this theory of Compton's is to-day one of the most important matters in physics. Section A of the British Association gave an afternoon at Toronto to the discussion of it. Prof. William Duane, of Harvard, is unable to verify Compton's experimental results, though he can get them by a slight yet significant modification of the apparatus. In a recent paper the statement was made that the establishing of Compton's theory carries with it the downfall of the current theory of radiation. G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE HYDROLYSIS OF AURAMINE.[1]

By Walter C. Holmes and J. Ferris Darling.

[ABSTRACT.]

DATA defining the dependence of the rate of hydrolysis of auramine in aqueous solution upon temperature and acidity have been recorded.

A volumetric method, which is of particular value in determining the quantity of auramines present in dye mixtures, may be based upon their hydrolysis.

Auramine G is appreciably more resistant to hydrolysis than is auramine.

THE NON-VOLATILE ACIDS OF THE PEACH.[2]

By E. K. Nelson.

[ABSTRACT.]

EXPERIMENTS conducted in the Bureau of Chemistry have shown that the non-volatile acids of the peach consist principally of a mixture of *l*-malic acid and citric acid in almost equal proportions.

CHEMISTRY AND CANDY MANUFACTURE.[3]

By H. S. Paine and J. Hamilton.

[ABSTRACT.]

FOR years the craft secrets of the confectionery industry have been guarded jealously and handed down from generation to generation. The chemist has played no part in the development of this industry. As a consequence, few of the procedures in

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Chem. Soc.*, **46** (October, 1924) : 2343.

[2] Published in *J. Am. Chem. Soc.*, **46** (October, 1924) : 2337.

[3] Published in *Confectioners J.*, **50** (June, July, August, 1924) : 91, 87, 87; and in *The Manufacturing Confectioner*, **4** (May, July, and August, 1924) : 26, 16, 22. Somewhat same subject-matter was published in *Ind. Eng. Chem.*, **16** (May, 1924) : 513, under title "Constructive Chemistry in Relation to Confectionery Manufacture."

candy manufacture have been interpreted from the standpoint of the chemical and physical theories governing them.

In their expert manipulations of syrups, crystallization of sugar, and the like, candy makers are really dealing with sugar chemistry, although they may not be aware of it. Obviously, therefore, a knowledge of the chemical laws upon which their operations are based will go a long way in clearing up the difficulties they now encounter.

With this end in view, the Bureau of Chemistry has conducted an investigation of the fondant type of candy which has shown that the application of chemistry may affect the various manufacturing processes and the character of the finished product. Chemistry in the confectionery industry need no longer be confined to the analytical control of raw materials.

Further experiments along this line have shown that invertase may be successfully and economically used in making candy of the fondant type.

Stainless Chromium Steels.—These alloys have attracted a great deal of attention of recent years, and W. H. HATFIELD, of the Brown-Firth Laboratories, of Sheffield, England, has presented a paper on some recent investigations concerning them. The presence of chromium in steel increases its resistance to nitric acid, but when present in large amount the solubility in hydrochloric and sulphuric acid is increased. There is evidence that the presence of chromium under strongly oxidizing influence permits of the immediate modification of the surface of the metal, in such a way as to produce complete passivity under certain conditions of temperature and concentration of the corroding media. As might be expected, the presence of colloids modifies the action of corroding agents.

An appendix contains a list of media that the stainless steel resisted and those which it did not. The items in both cases are numerous. Malt vinegar, for example, had a low corrosive action while acetic acid vapor was corrosive. Vinegar, lemon juice and sour milk are not very active on the steel, but the isolated acids in the same strength as in the organic mixture do attack it. These results agree with those that were announced not long ago by other investigators. (*Proceedings of the American Electrochemical Society*, October, 1924.)

H. L.

NOTES FROM THE U. S. BUREAU OF MINES.*

AIR RESISTANCE CAUSED BY MINE CARS IN COAL-MINE ENTRIES.

By J. W. Paul, H. P. Greenwald, and G. E. McElroy.

THE bureau is conducting an extensive research on coal-mine ventilation factors. After the resistance of an unobstructed entry to flow of air had been determined by tests in the Experimental Mine, mine cars were run into the test section in various arrangements and the increase in resistance was determined. Tests were made to determine the effect of: (1) Varying the number of cars in a trip; (2) varying the position of the trip; (3) varying the distance between cars; and (4) varying the size of a car. Tests were also made to compare the resistance of empty and loaded cars, and to compare the resistance of cars when in unbroken entry and when opposite to cut-through dead ends. It was found that the "end" resistance of a single car was three times the "side" resistance, and, consequently, 75 per cent. of the total resistance. The end resistance will probably vary as some power of the ratio of end surface area of the car to the cross-sectional area of the entry. The side resistance will vary with the length of the car, the character of the surfaces over which the air rubs, and inversely with some power of the clear area left for the passage of the air. Further research is necessary to determine these relations exactly.

When two or more cars are coupled together, the end resistance is the same as that of a single car. The side resistance, however, is the resistance of a single car multiplied by the number of cars, and the total resistance is the sum of the end and side resistances, assuming a uniform entry in all cases.

When two cars which have been coupled together are moved apart, the resistance increases to a maximum at about twenty-five feet between bumpers.

The difference in resistance between loaded and empty cars was of no practical significance, and cars had the same resistance when in unbroken entry and when opposite cut-through dead ends. The resistance caused by cars was independent of the veloc-

* Communicated by the Director.

ity of the air within the limits of error of the present experiments. The pressure loss varied with the square of the air velocity measured in clear entry or, stating the same thing in another way, it varied with the square of the volume of air passing per unit time. Further details are shown in Serial 2647.

IMPROVEMENT OF THE GEOPHONE BY ELECTRICAL SOUND AMPLIFIERS.

By Walter T. Ackley, Jr., and Clifton M. Ralph.

IN ITS study of methods of underground signalling, the Bureau of Mines considered the geophone as a possible means, but came to the conclusion for mine rescue work that in its present form it had two major limitations, namely, (1) communication is impossible, except where predetermined signals have been arranged, and (2) extraneous noises limit the use of the geophone for picking up weak signals.

As the use of electrical amplifiers seemed to be the most practical method of attacking the problem, their adaptation to the geophone was sought, by greater amplification of the air pulsations.

The recent development of the electron vacuum tube for amplification presents a field for the intensifying of geophonic sounds. Not only maximum, but true sound or reproduction without distortion must be obtained with the apparatus readily portable, rugged in construction, minimum upkeep and adjustment, and not affected by rough handling. The dry-cell tube with suitable resilient socket mountings apparently comes nearest to fulfilling these requirements.

With the electron tube method of amplification there are three stages, namely, (1) converting sound waves of the geophone into electrical waves; (2) amplifying electrical waves to the desired intensity; and (3) reproduction of electrical waves into sound waves. The results of preliminary experiments proved that the magnetic type of sound converter had possibilities of being adapted for converting sound waves into electrical waves, so work along this line finally produced an instrument which comes nearer to meeting the requirements for maximum sensitivity than any hitherto tried. A more complete description of the device will be found in Serial 2639.

Because of the limited time available, only one geophone with

its auxiliary amplifier was constructed. Although the principles upon which the electrical geophone operates appear to be fundamentally correct, it is not possible to state whether two such devices will function with exactly the same degree of magnitude. By proper design and adjustment this can probably be accomplished without greatly complicating the design. Inasmuch as audio-frequency amplification is used, no tuning is necessary as is the case with tuned radio-frequency circuits. The same filament and plate batteries can be used to operate the amplifiers and by the use of dry-cell tubes, requiring small filament and plate currents, it is believed that a compact, portable and practical instrument can be evolved.

MAGNETIC RECOVERY OF COMBUSTIBLE IN BOILER PLANT REFUSE.

By Rudolph Kudlich.

The realization that fuel costs, high as compared with those enjoyed prior to the war, are apparently permanent, has caused steam-power plant operators to apply their best efforts towards improving the fuel economy of their plants. Though they have given much attention to the reduction in combustion losses by improving methods of firing and improved equipment, and to diminishing the heat losses by more care in maintaining clean heating surfaces and tight and adequate baffling, they have almost universally neglected the waste that occurs from discarding unconsumed combustible with the boiler refuse. In actual operating practice the amount of unconsumed combustible in the boiler refuse may range from a few per cent. to as high as 40 or 50 per cent.

Though in America we have paid little attention to such recovery, in Europe considerable experimenting has resulted in the development of several types of machines for reclaiming combustible matter from boiler or furnace refuse. While the operation of most of these machines is by wet separation, either by flotation or by jigging, one machine operating on the magnetic principle has proved satisfactory, and judging by notices appearing from time to time in the technical press, quite a number of installations have been made.

By this method a more or less complete separation of the ash from the combustible is possible, depending on the amount of iron

present. Tests reported by a German firm using a magnetic drum type separator showed recoveries up to 87 per cent. of the combustible in the refuse. An American firm in making tests of magnetic recovery of combustible were able to recover approximately 50 per cent. of the combustible with a standard magnetic separator when crushing the refuse to three-quarters inch and smaller. A special separator with characteristics adapted to the material treated would probably give a greatly increased recovery. More complete details are shown in Serial 2634.

TENTH SEMI-ANNUAL MOTOR GASOLINE SURVEY.

By N. F. LeJeune and B. A. Landry.

FOR a number of years the Bureau of Mines has conducted semi-annual surveys to determine the changes in the characteristics of the motor gasoline being sold in the United States.

The Bureau of Mines surveys from April, 1917, to January, 1923, indicated a progressive decrease in the end point range. The survey for July, 1923, showed an interruption in this progressive decrease.

In comparison with the July, 1923, survey, it seems that a better grade of gasoline is now being marketed than during the same season a year ago. Comparison of the averages for the nine districts shows that there was an appreciable decrease in the initial boiling point, a decrease in the end point and 20 per cent. point, and an increase in the 90 per cent. point.

As compared with the survey of January, 1924, the seasonal variation from winter to summer grades is not so marked, although there is a slight increase in the averages for initial boiling point. Tabulated results of the survey will be found in Serial 2636.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, November 19, 1924.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 19, 1924.

PRESIDENT DR. WM. C. L. EGLIN *in the Chair.*

Additions to membership since last report, 15.

The Chairman recognized Dr. James Barnes who, on behalf of the Committee on Science and the Arts, introduced Mr. William F. Zimmermann, of Newark, New Jersey, to whom was awarded the Edward Longstreth Medal for his invention of a hob for cutting worm gears and the method of making it. The Chairman presented the medal and certificate to Mr. Zimmermann.

Action on the proposed new By-Laws, recommended for adoption by the Board of Managers, was deferred until the December meeting in order that the members may give the matter more careful consideration.

The paper of the evening was presented by Dr. Harrison E. Howe, Editor of *Industrial and Engineering Chemistry*, Washington, D. C., on "The Trend and Purpose of Modern Research." The frequent statements made concerning the importance of research, the constant appeals for funds to support it, and the increasing difficulty of giving publication to highly scientific research papers properly give rise to the questions: What is the trend and purpose of modern research? In what directions are the natural sciences, and particularly chemistry, headed? Are their problems such that if successful solutions were found the race may be expected to benefit? Answers to such questions are to be found in the types of problems being studied, particularly in the borderlands that exist between chemistry and biology, chemistry and physics, and chemistry as applied to the several major groups of engineering. The speaker discussed a few of the problems that have to do with transportation communication, public health and longevity, and indicated some of the work in progress and some of the problems listed under the heading of the chemist's unfinished business. The Chairman extended the thanks of the meeting to Doctor Howe for the very interesting paper.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 5, 1924.)

HALL OF THE INSTITUTE,
PHILADELPHIA, November 5, 1924.

MR. GEORGE H. BENZON, JR., *in the Chair.*

The following report was presented for final reading:

No. 2811: The Hob Used in the Cutting of Worm Gears and the Method of Making It. The Edward Longstreth Medal was awarded to Mr. W. F. Zimmermann, of Newark, New Jersey.

The Sub-committee having in charge the investigation of this device reported in part as follows: The methods of threading a single worm gear on a lathe and of milling it with a disc cutter have already been in use. The method under investigation consists of the use of a specially shaped hob or cutter, described in United States Patent No. 1,430,485, granted to William F. Zimmermann, on September 26, 1922.

"In cutting a single thread worm, the hob is initially set to the full depth of the tooth to be cut into the worm blank, and, apart from the feed movement, both the hob and the worm blank are rotated at the same angular speed in the same direction of rotation, the hob being fed into the blank in the direction of its axis of rotation. The threads of the hob have the teeth consecutively truncated so that the last tooth is really the shallowest."

The setting of the axes of both the hob and the blank are at such an angle and the direction of the feed of each is such that each successive cutter of the hob deepens the groove made by the previous cutter, the last cutter leaving the groove in its finished form.

The following report was presented for first reading:

No. 2791: Nachod Electric Railway Signal System.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, November 12, 1924.)

RESIDENT MEMBERS.

MR. CLARK DILLENBECK, Civil Engineer, 522 Reading Terminal, Philadelphia, Pennsylvania.

MR. T. R. HARRISON, Research Manager, The Brown Instrument Company, Philadelphia, Pennsylvania.

MR. E. S. HIGGINS, General Manager, Yellow Cab Company, 1734 North Broad Street, Philadelphia, Pennsylvania.

MR. WILFRED HOWARD, Instructor in Physics, Bryn Athyn, Montgomery County, Pennsylvania.

MR. EUGENE R. MANNING, Chemical Engineer, 32 West Ridley Avenue, Ridley Park, Pennsylvania.

MR. W. W. ROBINSON, Ship and Yacht Builder, 6446 Sherwood Road, Overbrook, Philadelphia, Pennsylvania.

NON-RESIDENT MEMBERS.

MR. ROBERT CRAIG, Consulting Engineer, Schwind Building, Dayton, Ohio.

MR. G. J. DOUGHERTY, Consulting Mechanical and Electrical Engineer, Room 719, 149 Broadway, New York City, New York.

DEAN RUSSELL E. LAWRENCE, Dean of Engineering, University of Detroit, 630 East Jefferson Avenue, Detroit, Michigan.

PROF. JOHN P. MORRISSEY, Professor of Chemistry, University of Detroit, 651 East Jefferson Avenue, Detroit, Michigan.

MR. RODOLPHO ORTENBLAD, Electrical Engineer, Union College, N.S., N.C., Schenectady, New York.

MR. FRANK W. PEEK, JR., Consulting and Research Electrical Engineer, General Electric Company, Pittsfield, Massachusetts.

DR. L. P. SIEG, Professor of Physics, University of Pittsburgh, Pittsburgh, Pennsylvania.

NON-RESIDENT LIFE MEMBERS.

MR. WALTER PETERSON, President, Atlantic Coal Company of Massachusetts, 80 Federal Street, Boston, Massachusetts.

ASSOCIATE MEMBERS.

MR. EDWARD L. ZIESEL, Chemistry Student, 909 West Lehigh Avenue, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

MR. STERLING H. BUNNELL, 347 Madison Avenue, New York City, New York.

MR. JOHN A. CAPP, 1309 Union Street, Schenectady, New York.

MR. WARNER G. EARNSHAW, 128 South Nineteenth Street, Philadelphia, Pennsylvania.

MR. JOHN STUART EASON, Room 950 Transportation Building, 608 South Dearborn Street, Chicago, Illinois.

MR. ALFRED ERNE, 20 East Athens Avenue, Ardmore, Pennsylvania.

MR. FRANK R. GARMAN, 416 Seventh Avenue, Pittsburgh, Pennsylvania.

MR. J. H. GRAVELL, in care of American Chemical Paint Company, Ambler, Pennsylvania.

MR. W. O. GRIFFITH, 500 East Evergreen Avenue, Chestnut Hill, Philadelphia, Pennsylvania.

MR. CHARLES F. KELLERS, M.S., N.C., Union College, Schenectady, New York.

MR. C. M. KLINE, 105 North Fifth Street, Philadelphia, Pennsylvania.

MR. VICTOR LENHER, 1718 Summit Avenue, Madison, Wisconsin.

DR. P. G. NUTTING, 1644 Irving Street, Washington, District of Columbia.

MR. SAMUEL SHOEMAKER, 1214–15 Franklin Trust Building, 1500 Chestnut Street, Philadelphia, Pennsylvania.

MR. S. D. SPRONG, Room 303, 44 Whitehall Street, New York City, New York.

MR. CARL D. ULMER, in care of The Koppers Company, 1329 Peoples Gas Building, Chicago, Illinois.

NECROLOGY.

Mr. George Burnham, Jr., 1400 Morris Building, Philadelphia, Pennsylvania.

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BOOK REVIEWS.

COLLOID CHEMISTRY. An introduction with some practical applications, by Jerome Alexander, M.Sc. Second edition, revised and enlarged, viii–208 pages, illustrated, 12mo. New York, D. Van Nostrand Company, 1924. Price, $2.

The author of this work is well known for his long and earnest labors in the field of colloid chemistry and for his valuable contributions to its literature. The book in hand, being a second edition, requires but little criticism. The fact that a new issue has been needed is evidence of the value of the text. An inspection shows that commendation is well-deserved. The text presents a clear and concise exposition of the chemistry and physics of colloids. Most of the books on this subject seem to the reviewer to be unnecessarily abstruse. Colloid chemists (we may speak in this manner, although these chemists are no more colloidal than other folks) are as a rule very enthusiastic and inclined to find colloidal conditions everywhere. Rising from a perusal of Wolfgang Ostwald's "Kolloidchemie," the present reviewer felt as though Ostwald might be disposed to regard the primordial chaos as a colloid and the fiat of creation as a flocculation thereof. Undoubtedly, however, Graham's work in the '60's of the last century was the beginning of a method of unravelling many problems of chemistry and physics. As with some other departments of chemistry, such as the study of the atom and of radio-activity, the progress of research has tended strongly to absorb chemistry into physics, and, as a result, a large proportion of practising chemists are giving but little attention to the physical side of the science, regarding it as having but little bearing on actual laboratory problems. A book like the one in hand will serve to correct this tendency, for here the general principles of colloid nature and actions are simply and vividly set forth. The book will also be of use to the teacher of general chemistry, for many instructive experiments are given. The author, of course, partakes considerably of the enthusiasm of writers and workers in this field. It seems that the time is now at hand for a book on "Crystalloid Chemistry."

HENRY LEFFMANN.

THE CHEMISTRY OF ENZYME ACTIONS. By K. George Falk, Harriman Research Laboratory, New York. Second and revised edition, 249 pages, numerous illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1924. Price, $3.50.

The first edition of this book appeared in 1921. It is one of the series of monographs published by the American Chemical Society which have been frequently noticed in this JOURNAL. The second edition is nearly double the number of pages of the first, which is an evidence not only of the author's industry in keeping up with the literature, but of the extensive development which this field has undergone. From the preface we learn that in many parts of the world, work is going on in studying enzyme actions. The available material is increasing rapidly but, as might be expected, the chemistry of the subject has not yet approached final development. Undoubtedly a very large proportion of chemical changes, especially those occurring in living organisms,

are the results of actions of substances of the nature of enzymes. Chemical procedure has not yet succeeded in giving us an absolutely pure enzyme.

The text is divided into ten sections as follows: Introduction, Velocities of Chemical Reactions, Chemical Reactions Catalyzed by Enzymes, Physical Properties Common to Enzyme Preparations, Chemical Properties Common to the Same, Chemical Nature of Certain Enzymes, Mechanism of Enzyme Actions, Uses and Applications of Enzymes, Enzyme Actions of Tissues and Tumors, and the Present Status of Enzyme Problem. In the introduction the author defines enzymes as catalysts found in living matter. The word "catalyst" therefore is to be understood as of a broader significance, and this is probably the preferable view and indeed it might be said that the word "enzyme" might disappear from the literature and the word "catalyst" take its place in all cases. Neither word is directly related in etymology to the phenomena brought about by the substances. Catalytic actions in inorganic matter are very common. One of the earliest and a still unexplained action is that by which manganese dioxide causes the decomposition of potassium chlorate. This was discovered in 1832 by Döbereiner. The announcement was made four years before Berzelius introduced the word "catalyst" into chemistry. Since Döbereiner's time very many striking and valuable instances of catalytic action have been discovered. One of the most important is that by which platinum acts to promote the union of sulphur dioxide and oxygen, constituting the basis of the contact method of manufacturing sulphuric acid. Another instance of an inorganic catalyst is seen in the Welsbach mantle. When this is made of thorium oxide alone the light is unpleasant, but the addition of a small amount of cerium oxide makes the light bearable.

Concerning the book in hand, it is sufficient to say that it is a very comprehensive and clear statement of the subject. The chapter on "Enzyme Actions of Tissues and Tumors" will undoubtedly be valuable to pathologists. The author points out that enzyme reactions may be divided into two general classes. In one class the elements of water, or of some similar compound, may be added to, or eliminated from, the substance that is changed. In the other, oxidation or reduction occurs. The second class is considered somewhat more in detail. Oxidation or reduction refers in any given case to one or more definite atoms of a molecule and not to the molecule as a whole. In inorganic compounds the view has generally been accepted that oxidation consists of an increase in the positive charge of the oxidized atom or a decrease in the negative charge. Using the electron conception of valence, these views become simplified and applicable to all classes of compounds. This conception is that in the formation of a union or linking between two atoms, one of these loses an electron and the other gains it. As the result of this, one atom requires a unit positive charge and the second a unit negative charge. In oxidation the valence of the atom oxidized is increased and reduction decreased. The author proceeds to illustrate this in the case of ferrous into ferric chloride and in the change from hydrogen sulphide to sulphur dioxide. The theories of the action from this point of view are presented in considerable detail, and it is therefore very interesting and valuable to see the newer views of atomic structure brought into active relations with this department of chemistry.

HENRY LEFFMANN.

HELMHOLTZ'S TREATISE ON PHYSIOLOGICAL OPTICS. Edited by James P. C. Southall, Columbia University. Vol. I, xxi–482 pages, illustrations, large 8vo. Published by The Optical Society of America, 1924. Price, $7.

This edition, issued as noted by The Optical Society of America, is for sale only through Cornell University, Ithaca, New York, in care of Prof. F. K. Richtmyer.

Helmholtz needs no introduction to any student in the physical sciences. His name stands out prominently in the history of research, especially in the subjects of light and vision. He, however, also worked, as is well known, in the acoustic field. He began his scientific researches early in life and continued them through a long series of years. The third German edition of his work on physiological optics was published after his death and was greatly enlarged by the collaboration of several eminent German workers. No English translation, however, was prepared nor is there any work originally in English which fills the place of Helmholtz's treatise. It is noted in the preface to the English translation that both Young and Helmholtz, who share in the service to mankind in research in these important fields, were trained in the medical profession and yet each gained his greatest renown in the purely non-medical investigations, although these investigations are more or less intimately related to the problems of medical practice.

The present translation was brought about by a suggestion made at the celebration of the hundredth anniversary of Helmholtz's birth by The Optical Society of America in 1921 at Rochester, New York. It was thought that it would be a most fitting tribute to the memory of the great scientist to present in English form a translation of his important contribution. A special committee was appointed for the purpose, and it decided to employ the third German edition, not only because it was the last definitive edition, but also contained the original Helmholtz text, supplemented and enriched by recent additions by experts in the several departments.

The preparation and publication of this treatise involved a great deal more expense and labor than was anticipated. Mr. Adolph Lomb, whose name is well known in the field of optical apparatus, made it his earnest purpose to bring this plan to successful termination. The presentation of a work of this kind in English will not only be a welcome incident to the scientific workers in the field to which it is devoted, but will have the further value of encouraging research and publication by English-speaking scientists. The Editor has received the assistance of a considerable number of specialists whose names are duly recorded in the preface, and he has labored with success to render the German into idiomatic English and yet preserve the exact sense of the original. This is perhaps as difficult a task as may offer in translation. The syntax in the German language differs so greatly from English syntax that there is a constant danger that the translator, working steadily for hours upon the German text, will unconsciously fall into its methods of phrasing and thus produce awkward and sometimes unintelligible expressions. This has been avoided in this translation. Very little of this class of error is observed. The Editor assumes entire responsibility for any such errors that may be observed.

The work does not claim to be a new edition of the "Physiological Optics" of Helmholtz, but it does contain considerable new and original material, the

items of which are given specifically in the preface. With some slight modifications the plates and illustrations have been reproduced from the original engravings, purchased from the German publishers. These publishers have been most friendly in their attitude toward the publication and have striven to make the English edition in every way worthy of the German one and of the distinguished author. The mechanical execution of the book is entirely commendable. The present work, as noted, is the first volume. The entire treatise will appear in three volumes, the manuscript for the second being now in the hands of the printers. The translation of the preface to the first edition, dated December, 1866, is presented in the volume and also an extensive preface to the third edition by W. Nagel, dated September, 1909. Volume I is devoted to the following main subjects: The Anatomy of the Eye and the Dioptrics of the Eye, with appendices by A. Gullstrand.

The work is very extensive, elaborate and comprehensive and will constitute, therefore, a most valuable addition to the literature in the field available to English-speaking students. HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 197, A New Relation between the Induced Yawing Moment and the Rolling Moment of an Airfoil in Straight Motion, by Max M. Munk. 7 pages, illustrations, quarto. Washington, Government Printing Office, 1924. Price, five cents.

In this paper, prepared for the Committee, the induced yawing moment, due to the rolling moment produced by the ailerons, is computed. This induced yawing moment is the greatest part of the entire yawing moment encountered by the wings. The following approximate formula results:

$$\frac{\text{Induced yawing moment}}{\text{Rolling moment}} \text{ is about } \frac{\text{Lift coefficient}}{\text{Aspect ratio}}.$$

Report No. 198, Astronomical Methods in Aerial Navigation, by K. Hilding Beij. 52 pages, illustrations, quarto. Washington, Government Printing Office, 1924. Price, fifteen cents.

This report was prepared by the Aeronautic Instruments Section of the Bureau of Standards, at the request of the National Advisory Committee for Aeronautics. A part of the material was made available by the courtesy of the War Department, from the results of investigations carried out at the Bureau of Standards for the Army Air Service.

The astronomical method of determining position is universally used in marine navigation and may also be of service in aerial navigation. The practical application of the method, however, must be modified and adapted to conform to the requirements of aviation. Much of this work of adaptation has already been accomplished, but, being scattered through various technical journals in a number of languages, is not readily available. This report is for the purpose of collecting under one cover such previous work as appears to be of value to the aerial navigator, comparing instruments and methods, indicating the best practice, and suggesting future developments.

The various methods of determining position and their application and value are outlined, and a brief résumé of the theory of the astronomical method is given. Observation instruments are described in detail. A complete

discussion of the reduction of observations follows, including a rapid method of finding position from the altitudes of two stars. Maps and map cases are briefly considered. A bibliography of the subject is appended.

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Introduction to Organic Research. By E. Emmet Reid, Professor of Organic Chemistry, Johns Hopkins University. 343 pages, 8vo. New York, D. Van Nostrand Company, 1924. Price, $5.

The Elements of Machine Design. By S. J. Berard, Assistant Professor of Drawing and Machine Design, Brown University, and E. O. Waters, Assistant Professor of Machine Design, Sheffield Scientific School, Yale University. 323 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1924. Price, $2.50.

Quantitative Organic Microanalysis. By Fritz Pregl, D.Sc., Ph.D. Translated from the second revised and enlarged German edition by Ernest Tyleman, B.S., Ph.D. 190 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1924. Price, $4.

The Recent Development of Physical Science. By William Cecil Dampier Whetham, M.A., F.R.S. 313 pages, illustrations, 12mo. Philadelphia, P. Blakiston's Son and Company, 1924. Price, $3.

Principles and Applications of Electrochemistry. In two volumes, Vol. I—Principles, by H. Jermain Creighton, Associate Professor of Chemistry, Swarthmore College. 446 pages, illustrations, 8vo. New York, John Wiley and Sons, Incorporated, 1924. Price, $4.

Ontario Department of Mines. Thirty-first Annual Report being Vol. XXXI, Part II, 1922. Geology of the Mine Workings of Cobalt and South Lorrain Silver Areas, by Cyril W. Knight, together with a Description of Milling and Metallurgical Practice in Treatment of Silver Ores at Cobalt, by Fraser D. Reid, James J. Denny and R. H. Hutchison. 374 pages, illustrations, plates, maps, diagrams, 8vo. Toronto, King's Printer, 1924.

National Electric Light Association. Prime Movers Committee, Serial Report: Boilers, Superheaters and Economizers. 57 pages, illustrations, quarto. Fuel Specifications. 5 pages, quarto. Oil and Gas Engines. 16 pages, illustrations, quarto. Turbines. 19 pages, illustrations, quarto. New York, Association, 1924.

The Kinetic Theory of Gases. By Eugène Bloch. Translated by P. A. Smith, B.A. 178 pages, illustrations, 12mo. New York, E. P. Dutton and Company, no date. Price, $3.

Faraday Society and the Institute of Metals. Fluxes and Slags in Metal Melting and Working. A general discussion. Reprinted from the transactions of the Faraday Society, Vol. xx, part 1. 98 pages, illustrations, 8vo. London, 1924.

U. S. Department of Agriculture. Department Bulletin No. 1259. Standard Specifications for Steel Highway Bridges, Adopted by the American Association of State Highway Officials. 48 pages, 8vo. Washington, Government Printing Office, 1924. Price, ten cents.

National Advisory Committee for Aeronautics. Technical Notes, No.

206. Structural Weight of Aircraft as Affected by the System of Design, by Charles Ward Hall. 21 pages, photographs, quarto. No. 207. The Simplifying Assumptions, Reducing the Strict Application of Classical Hydrodynamics to Practical Aeronautical Computations, by Max M. Munk. 16 pages, quarto. Washington, Committee, 1924.

Diffraction Bands Formed by X-rays about the Photographic Image of a Slit. B. WALTER. (*Ann. d. Physik*, No. 15, 1924.)—It was first of all necessary to get X-rays as nearly monochromatic as possible. After trying a molybdenum anti-cathode, copper was found to be better for the purpose because its two characteristic lines are of twice the wave-length of those of the former metal, so that the bands from the radiation emitted by copper would be separated by a greater distance than in the case of molybdenum. Furthermore the interposition of a sheet of nickel .01 mm. thick in the path of the rays from the copper anti-cathode cut out one line almost entirely, thus leaving the transmitted ray nearly of a single wave-length. This radiation then passed through a slit .006 mm. wide and then through a second slit, 75 cm. distant from the first, that was in the form of a wedge, tapering in its length of 18 mm. from a width of .04 to .00 mm. To prevent too great a reduction in the intensity of the rays by absorption in air, two vacuous tubes were inserted in the path of the rays, one between the two slits and the other between the photographic plate and the wedge-shaped slit. The experiment is essentially an attempt to photograph the bands about the wedge-shaped slit, radiation of wave-length 1.54×10^{-8} cm. being used. Reproductions in 76-fold magnification of the photographs obtained by an exposure of thirty hours are given. It is quite easy to see the dark diffraction band nearest to the wide central band. The author claims to see the second also and from its distance from the central band calculates the wave-length of the radiation employed to be 1.31×10^{-8} cm. This is about 15 per cent. less than the correct value. The intensities of the two bands are, it is stated, in accordance with theory.

The results of this investigation are of great importance because they confirm from an additional line of argument the identity of X-rays with light except in the single feature of difference in wave-length. G. F. S.

The Solar Constant and Weather Prediction. (Explorations and Field-work of the Smithsonian Institution in 1923. Smithsonian Mis. Coll., Vol. 76, No. 10.)—"The late Secretary Langley used often to express his prevision that the study of the sun's heat, the losses that it suffers in passing through our atmosphere, the variations which it may be subject to, would at length serve to forecast the changes of weather and climate which are so important for the agriculturist, and which in some parts of the world even lead to periods of disastrous famine. He used to speak of Joseph's seven years of plenty and seven years of famine, in this connection, and of the possibility that in the future the student of the sun might be in a position to emulate that ancient prophet."

The Smithsonian Astrophysical Observatory discovered that the quantity of heat received from the sun varies from year to year. Mr. Clayton, chief forecaster of the Argentine Meteorological Service, studied the connection between the sun's heat and the weather and believed he established the existence of a marked influence on the weather of Argentina. The earlier Smithsonian observations were conducted on Mt. Wilson, where the summer and autumn possess the cloudlessness necessary for successful work. In order to get observations throughout the entire year a station was set up at Calama, near the Nitrate Desert in Chile. This was in operation for two years "until July, 1920, when, by the advice and financial assistance of Mr. John A. Roebling, it was removed to the top of Mt. Montezuma, about ten miles south of the former location and high above the dust and smoke which had hindered to some extent the observations near Calama." With the assistance of the same patron and at the same time the Mt. Wilson apparatus was moved to the top of Mt. Harqua Hala, Arizona, a site whose suitability was determined with the assistance of the Weather Bureau.

Parallel with the occupation of stations more favorably situated went improvements in the working up of the observations. "The method of solar observations invented by Langley and developed by the Astrophysical Observatory requires a continuous uniform transparency of the sky for several hours, either in the early morning or the late afternoon. It also requires about twenty-five hours of measurement and computing for each day of observation." Great simplification has been introduced. "According to this newest method, the required observations for determination of the intensity of the sun's heat as it is outside the atmosphere can be secured in less than fifteen minutes, and the results can be computed in less than an hour, so that it is now possible and usual to make five daily determinations at each station of the intensity of the solar heat as it is outside the atmosphere, reduce these observations by one or two o'clock in the afternoon, and, again by Mr. Roebling's financial assistance, communicate them by telegraph to the Smithsonian Institution at Washington, where they are received early on the following morning. Now that five independent determinations are usually made daily at each station, the mean results are very accurate. . . . . Half of one per cent. is the average daily difference between the indications of the solar heat as it is outside the atmosphere, determined at these two stations many thousands of miles apart, one in the Northern, the other in the Southern Hemisphere, one at an altitude of 5000 feet, the other at 9000 feet."

During the years 1914–21 the solar energy outside of the atmosphere fell on a square centimetre at the rate of 1.95 calories per minute. Beginning in 1921 the so-called solar constant fell to a minimum in March, 1922, then came a rise up to early fall, 1923, from which time it declined again, in February, 1924, reaching a value of 1.92 calories. In a single year the fluctuations amount to as much as 4 per cent.

"The reader might think it obvious that if the solar radiation falls, the temperature would fall also. Nothing so simple as this occurs." The atmosphere absorbs about a quarter of the solar radiation and its heat capacity is very slight in comparison with that of the ocean and the solid earth combined. Hence of all parts of the earth the atmosphere would be expected to show the greatest and most immediate temperature effect. "But since the atmosphere is in some regions hazy, humid and cloudy, in other regions dry and transparent, the quantity of solar heat absorbed must vary much from place to place. The consequence is that air expansion, due to increased temperature accompanying increase of solar radiation, takes place in much larger proportion in the humid, hazy regions than it does in the cloudless clear ones, and so the air must flow from the regions of the former condition to those of the latter. This produces changes in barometric pressures which in turn produce the winds and cyclonic movements which are so familiar. This alters the direction of the winds and, as is well known, the temperature depends intimately on the prevailing wind at every locality. This may explain why it is that we are not to expect at every station and at every time of the year colder weather when the solar radiation is lower. We may have exactly the reverse depending on these secondary effects." G. F. S.

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